VOLUME LXXVI NUMBER 5

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

Edited by

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DECEMBER 1932

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NOTE ON THE ORIGIN OF CONTINUOUS COMETARY SPECTRA

By Willi M. Cohn

ABSTRACT

Various theories concerning the origin of the continuous spectra of comets are discussed. The solar type spectrum may be explained by the reflection of sunlight from large particles. Laboratory experiments show that continuous spectra may be produced by bombardment of ions of different materials with electrons in a high vacuum. A theory is developed which assumes that electrons are emitted constantly from the sun. These electrons will give rise to the violet type and, in the tail at a great distance from the head, to the solar type of continuous spectra observed in comets. The polarization phenomena of the light emitted by comets are explained by the new theory. The continuous spectra of straight and curved tails are expected to differ in the shift of the maximum with growing distance from the head. Band and line spectra observed in comets are assumed to be mainly excited by electrons emitted constantly from the sun.

Most of the comets which have been thoroughly investigated show bands, lines, and continuous spectra. In this paper I shall deal mainly with the continuous spectra of comets, giving first a short review of the spectra observed in the head and in the tail. After a discussion of existing theories on the origin of these spectra, I shall develop a theory based on laboratory investigations on the excitation of continuous spectra by electron bombardment in high vacuum, under the tentative assumption that electrons are emitted constantly from the sun.

I. CONTINUOUS SPECTRA OBSERVED IN COMETS

The investigations of H. Rosenberg, N. T. Bobrovnikoff, and others[1] have shown that two types of continuous spectra appear:

[1] A. Kopff, "Kometen und Meteore," *Handbuch der Astrophysik*, 4, 426, 1929.

(1) the "solar type," with a maximum of intensity (photographically determined) at about λ 4700; and (2) the "violet type," with a maximum (photographically determined) at about λ 4000.

When a comet's heliocentric distance is great, the violet type spectrum alone is present. As the comet approaches the sun, the solar type maximum makes its appearance in the spectrum, as shown by Bobrovnikoff's[1] microphotometer curves. The intensity of both maxima increases with approach to the sun—the solar type maximum, however, showing a much greater increase than the violet type. Finally, beginning at about 1.3–0.7 astronomical units from the sun, the solar type spectrum predominates and becomes so strong that the violet type maximum cannot be identified. As the comet recedes from the sun, the sequence of the two maxima is reversed; and at large heliocentric distances only the violet type remains. It is to be noted that the maximum of development of the spectrum is not found at perihelion but is retarded by about one or two weeks.

When the head exhibits the solar type spectrum, this spectrum is also observed in the adjacent part of the tail, as, for instance, in comet 1910 I.[2] The distribution of intensity in the continuous spectrum of the adjacent tail is, in most cases, almost identical with that of the nucleus. When comet 1908 III (Morehouse), which had a straight tail, showed the violet type spectrum in the head, a similar violet type spectrum was also present in the beginning of the tail, the maximum of intensity of both spectra being at λ 4000. Bobrovnikoff shows that with increasing distance from the head of this comet the maximum of the continuous spectrum is found at longer wave-lengths and at a great distance from the head the maximum in the tail is at λ 4700—a value similar to that of the solar type spectrum.

The development of the maxima of the two types of continuous spectra observed in the head is sometimes interrupted by violent changes in the spectra, as reported, for instance, by Bobrovnikoff:[3]

[1] *Astrophysical Journal*, **66**, 439, 1927.

[2] N. T. Bobrovnikoff, *Publications of the Astronomical Society of the Pacific*, **43**, 61, 1931.

[3] *Astrophysical Journal*, **66**, 145, 439, 1927.

The violet type spectrum predominated in comet 1910 II (Halley); on May 24 a sudden strong increase of intensity of the solar type spectrum was observed, and at the same time an explosion of the nucleus seemed to have taken place. After some time, the solar type spectrum weakened until the original violet type spectrum predominated again. In the case of comet 1914 V (Delavan) the opposite was observed. Nine hours after the solar type spectrum had predominated on September 30 the comet developed a strong spectrum of the violet type, which subsequently weakened and finally gave way to the original spectrum.

Up to the present, only a comparatively small number of observations on the polarization of the light of comets has been published. The polarization of the light of the coma showing the solar type spectrum seems to be caused by the light of the sun; the same polarization is also observed in the beginning of the tail. The light emitted by the nucleus does not indicate any polarization.[1] When the violet type spectrum is present, sometimes only a very small amount of polarization could be detected and sometimes none at all.

II. EXISTING THEORIES ON THE ORIGIN OF CONTINUOUS COMETARY SPECTRA

It is generally assumed that the solar type spectrum with a maximum of intensity at about λ 4700 is caused by reflection of sunlight from particles contained in the comet, which are large in comparison to the wave-lengths of the incident light. This theory is supported by several observed facts: the spectrum of the sun and the solar type spectrum of a comet display the same distribution of energy. The solar type spectrum of a comet is strongest near perihelion, and at the same time such bands and lines as may be assumed to be generated by expulsion of matter from the nucleus appear with great intensity. The reflection theory is also supported by the fact that Fraunhofer lines have been observed frequently in cometary spectra exhibiting the solar type. The sudden shifting of intensity from the violet to the solar type spectrum in comet Halley as mentioned above, together with the development of large quantities of gases, also supports the reflection theory.

[1] J. C. Duncan, *Lick Observatory Bulletins*, **4**, 171, 1907; W. W. Campbell, *ibid.*, **5**, 31, 1908.

The appearance of a continuous spectrum with a maximum at λ 4700 in the tail of comet Morehouse, at a large distance from the head, is attributed by Bobrovnikoff to reflection of direct sunlight. However, the microphotometer curves of this comet taken at a great distance from the nucleus never showed the appearance of the maxima at λ 4700 and λ 4000 in the same spectrum.

Several theories on the origin of the violet type spectrum with a maximum at about λ 4000 have been advanced, some of which may be mentioned here: J. Tyndall,[1] H. Rosenberg,[2] C. Fabry,[3] F. Baldet,[4] and other authors believe that the violet type spectrum may be caused by scattering of light from the sun by particles, which are small in comparison to the wave-lengths of the light incident from the sun (this would correspond to the theory of Tyndall and Lord Rayleigh, or to a similar law). However, the very small amount of polarization or its entire absence cannot be explained by this theory even when the turbid medium of a comet is considered as not ideal in the sense of Lord Rayleigh. The regularity of appearance and disappearance of the violet type spectrum, in spite of different phase angles of the comet, is also in opposition to this theory.

The tentative assumption of Bobrovnikoff which attributes the violet type spectrum to the emission of the continuous hydrogen spectrum or carbon monoxide and various organic hydrocarbons present in comets cannot be supported, as the distribution of energy in these spectra is different from that in continuous spectra of the comets (cf. W. Finkelnburg).[5]

K. Schwarzschild and E. Kron,[6] H. B. Lemon and N. T. Bobrovnikoff,[7] and N. T. Bobrovnikoff[8] conclude from their observations that the violet type spectrum is caused by fluorescence of cometary matter excited by the incident or reflected sunlight; the polarization is believed to be due to this fluorescence. I wish to point out, however,

[1] *Philosophical Magazine*, **37**, 241, 1869.

[2] *Astrophysical Journal*, **30**, 267, 1909. [3] *Journal de physique*, **7**, 89, 1917.

[4] "Recherches sur la constitution des comètes et sur les spectres du carbone." Thèses présentées à la Faculté des Sciences de Paris. Orléans, 1926.

[5] *Physikalische Zeitschrift*, **31**, 1, 1930.

[6] *Astrophysical Journal*, **34**, 342, 1911.

[7] *Nature*, **117**, 623, 1926. [8] *Astrophysical Journal*, **66**, 439, 1927.

that until recently fluorescence had not been observed in the laboratory to emit at low pressures a continuous spectrum similar to that observed in comets.

Whereas most of the bands and lines observed in the spectra of comets may be excited in the laboratory by means of electron bombardment of gases at low pressures, the influence of electrons or ions emitted from the sun is considered as not likely for the excitation of the band and line spectra observed; the main reason for this is that the aurorae which are believed to be caused by electrons emitted from sun-spots or their neighborhood appear occasionally in certain regions of the atmosphere, whereas in the case of comets the spectrum remains the same for long periods and usually occurs in the same regular sequence[1] in all comets investigated. For this reason Bobrovnikoff has proposed the theory that the rays of the sun produce a photoelectric effect in cometary matter. The theory advanced by A. Berberich[2] and J. Bosler,[3] suggesting a parallelism between the maxima of sun-spots and the brightness of comet Encke and assuming an effect of electrons from sun-spots on cometary matter, was not confirmed.[4]

III. NEW THEORY ON THE ORIGIN OF CONTINUOUS COMETARY SPECTRA

In several papers[5] I have shown that it is possible to excite, under certain conditions, a blue glow in the laboratory by means of electron bombardment. With solid bodies, the blue glow appears on the anode of different metals opposite a pointed cathode when the pressure is as low as $\leqq 10^{-5}$ mm Hg. When thorium, uranium, and polonium are used as anodes, the same glow covers the entire surface of the anode metals, the pressure ranging from $< 10^{-5}$ mm Hg to 1 atmosphere.

[1] H. Deslandres, A. Bernard, and J. Bosler, *Comptes rendus*, **148**, 805, 1909.

[2] *Astronomische Nachrichten*, **119**, 49, 1888.

[3] *Bulletin de la Société Astronomique de France*, **23**, 443, 1909.

[4] J. Holetschek, "Untersuchungen über die Grösse und Helligkeit der Kometen und ihrer Schweife. IV," *Denkschrift. Kaiserl. Akad. d. Wiss. Wien, mathem.-naturw. Klasse*, **93**, 1, 1916.

[5] W. M. Cohn, *Zeitschrift für Physik*, **70**, 662, 1931; *ibid.*, **70**, 667, 1931; *ibid.*, **70**, 679, 1931; *ibid.*, **72**, 392, 1931; *ibid.*, **73**, 662, 1932; *ibid.*, **75**, 599, 1932.

The blue glow emits unpolarized light and shows a continuous spectrum which is observed from 6800 to 2200 A; the maximum of intensity is found spectrographically at 4500 A. When the voltage is raised, the color of the glow becomes violet and the maximum of the continuous spectrum is shifted to 3600 A. Curves of the true distribution of spectral energy of the glows, which were obtained by comparison with black-body radiation, show the maxima of the blue and violet glows situated at 4650 and 3500 A, respectively.

It is possible to excite similar glows by electronic bombardment of vapors and gases at a pressure of about 10^{-4} mm Hg. The glows also exhibit unpolarized light and a continuous spectrum which could be observed for the blue glow from 6200 to 3000 A, the maximum being determined photographically at 4500 A. This blue glow is very similar to the glow observed from solid bodies, except that the spectrum shows a steeper decline toward shorter wave-lengths. Furthermore, this spectrum is independent of the materials investigated. I may further mention that in all cases when the glows appeared ions were found to be present. In what follows I shall point out that the continuous spectra of comets may be explained by means of the glows observed in the laboratory, if we assume that electrons are emitted from the sun.

Quite a number of independent observations point to the possibility that electrons are emitted from the sun. The experiments in connection with the theories of K. Birkeland and C. Störmer on the origin of auroras and magnetic disturbances and the investigations on the emission of electrons by bodies heated to high temperatures may be cited. The theory of Birkeland and Störmer deals with electrons emitted from sun-spots or their neighborhood and leads to electrons moving in well-defined paths, as calculated by Störmer, and arriving only in certain regions of the atmosphere near the magnetic poles or surrounding the equator of the earth.

It is not generally known, however, that C. Stormer[1] has also pointed out the possibility that electrons may be emitted from the entire surface of the sun. The speed of these electrons will remain the

[1] "Résultats des calculs numériques des trajectoires des corpuscules électriques dans le champ d'un aimant élémentaire. III. Spirale de Villard; trajectoires périodiques; modèle de la couronne du soleil etc.," *Vidensk.-Selsk. Skr.*, I, Mat.-naturv. Kl. 1913, No. 14.

same in the high vacuum of space unless they are scattered or absorbed on their way by matter. I have tried to base, on the calculations of Störmer and some observational facts, a theory which explains the appearance of the green line λ 5577 at night over the entire sky and some other phenomena of the atmosphere. The assumption has been made that electrons constantly strike the atmosphere of the earth.[1]

Calculations based on observations of comets, as well as experiments in the laboratory on the excitation of the band and line spectra of the tail, make it probable that the pressure in comets may be of the order of 10^{-4}–10^{-5} mm Hg or less, the pressure in the nucleus being somewhat higher than in the tail. If we assume now that electrons of a sufficient velocity are emitted constantly from the sun, we may conclude that the conditions in the comets are similar to those in the laboratory which produce the emission of the blue and violet glows by means of electronic bombardment. Scattering of sunlight by cometary matter, according to the theory of Tyndall and Lord Rayleigh, may also play a part in the production of the violet type spectrum.

With the theory outlined we may explain in a satisfactory way most of the observations mentioned above:

1. Electrons emitted from the sun will hit the gaseous matter of a comet and ionize at least part of it. Indeed, we observe in the comets bands of CO^+, N_2^+, etc.

2. Electrons striking the ions will excite a glow in comets which will emit a continuous spectrum; according to the speed of the electrons emitted from the sun, the maximum of the continuous spectrum is found at 4000 A in comets, i.e., at a wave-length between the limits of the maxima as hitherto observed in the laboratory.

3. The light emitted by the glow should be unpolarized according to the observations in the laboratory, whereas the scattered light should be entirely polarized, as observed by Tyndall. The light emitted by comets with the violet type spectrum is very slightly polarized or not at all. We may conclude therefore that the scattered light plays a very small part in comets in comparison to the light emitted by the glow excited by electrons from the sun.

[1] W. M. Cohn, *Gerlands Beiträge zur Geophysik*, October, 1932.

4. With approach of a comet to the sun the maximum of the violet glow spectrum should remain at the same wave-length, except that its intensity should be augmented as more electrons of a certain speed emitted from the sun may strike the comet, thus increasing the intensity of the glow in the same way as in the laboratory. This conclusion seems also to be confirmed by the observational data mentioned above.

5. Let us assume, now, that electrons strike a comet having a straight tail whose direction coincides with the prolongation of the radius vector. The electrons will then pass through the matter of the tail, and this matter will act as a turbid medium; consequently, the mean speed of the electrons should be diminished with growing distance from the head of the comet. From our laboratory experiments we know that with decreasing velocity of the electrons the maximum of the continuous spectrum of the glow is shifted to longer wave-lengths and results in the production of the blue glow. That is exactly what we observe in comets: with increasing distance from the head of the comet the maximum is shifted from 4000 to 4700 A in the tail of comet Morehouse as observed by Bobrovnikoff.

Our theory leads us to expect that a curved tail of a comet should exhibit a spectrum different from that of a straight tail: the electrons are assumed to move in almost straight paths within not too large a distance from the sun; they will always strike the matter of the tail with the same velocity, and accordingly the maximum of the continuous spectrum should remain at the same place. However, in no case known to me has a curved tail been investigated in the same thorough manner as the straight tails, and the position of its maximum with growing distance from the head has not been determined exactly. The only remark in this respect which I could find is contained in a paper by Bobrovnikoff,[1] who mentions that the strongly curved tail of Halley's comet showed the solar type spectrum "without appreciably changing the position of the maximum of intensity in its spectrum."

Thus we expect a certain parallelism between the new theory and the one of T. Bredichin,[2] who believed that there are different types

[1] *Publications of the Astronomical Society of the Pacific*, **42**, 309, 1930.

[2] *Mechanische Untersuchungen über Cometenformen, St. Petersburg*. Leipzig, 1903.

of band and line spectra in comets having straight and curved tails, a prediction which has not been confirmed by recent investigations.

6. The motion of matter and the formation of cometary tails observed is usually assumed to be caused by a repulsive force emanating from the sun. Among the theories advanced to explain the nature of the repulsive force, the most satisfactory seems to be the assumption of light pressure acting on the matter of comets (cf., for instance, the review by A. Kopff[1]). Recent investigations of Bobrovnikoff and others show, however, that the repulsive force seems not to be constant and that there probably exists a repulsive force emanating from the nucleus.

The theory advanced above, that electrons are emitted from the sun, leads to the tentative suggestion that these may also be responsible, at least partially, for the repulsive forces observed. Thus, we would have a combined action of light pressure and electrons emanating from the sun and from the nucleus, on the matter of comets.

Thus we may conclude that the violet type spectrum of comets is caused by electrons emitted from the sun and that the solar type spectrum as observed with the approach of comets to perihelion is produced by reflection from larger particles developed in the comet with decreasing heliocentric distance. The solar type spectrum in the tail, however (at a large distance from the head), may be explained by electronic bombardment of cometary matter. Scattered light may contribute a small amount to the appearance of the violet type spectrum.

The sudden appearance of the violet type spectrum in comet 1914 v (Delavan), as mentioned above, would indicate, on the basis of our theory, an increased solar activity. However, I could find no record of observations which would confirm this assumption.

CAMBRIDGE, MASSACHUSETTS
October 1931

[1] *Loc. cit.*

THE LIMITING MAGNITUDE OBSERVABLE WITH A PHOTOELECTRIC STELLAR PHOTOMETER[1]

By SINCLAIR SMITH

ABSTRACT

Random *fluctuations* in the *number of photoelectrons* produced per second are shown to set an assignable lower *limit* to the useful *sensitivity of a photoelectric cell*. The case of a potassium hydride cell attached to the 60-inch reflector is treated numerically, and the minimum time intervals during which photoelectrons must be collected in order to make 1 per cent measurements on the light from a star of a given magnitude are tabulated.

Since Elster and Geitel developed the first useful photoelectric cells, these cells have found ever wider application to the precise measurement of the intensity of radiation. Much is known about cells of various types, such as their response to different wavelengths, their voltage characteristics, etc., but thus far only very meager information about the lower limit of their useful sensitivity has been available. By "useful sensitivity" is meant the limit set by the condition that the response of the cell must be reproducible within some assigned range, which is of course arbitrary. This range having been assigned, it becomes important, however, to know whether or not a photoelectric cell is capable of yielding the desired result, for without this knowledge much effort may be wasted in devising very delicate instruments to do impossible things.

A lower limit to the sensitivity of a cell must exist, for, since only one quantum in 10^2–10^3 produces an electron, large fluctuations in the response, measured say in electrons per second, must appear if the number of quanta arriving per second is small. As has been shown in a very careful study by E. Steinke,[2] these fluctuations obey the usual laws of probability, but before taking up the calculations

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 457. This work was undertaken as a part of a co-operative study of astrophysical instruments and methods, made in connection with the development of the Astrophysical Observatory and Laboratory of the California Institute of Technology.

[2] *Zeitschrift für Physik*, **38**, 378, 1926.

in detail, let us make sure that other factors are not of equal or greater importance.

Consider a simple vacuum cell, consisting usually of a highly evacuated bulb of glass or quartz into which are sealed two electrodes. One of these electrodes is connected with the light-sensitive surface (either separately mounted or deposited on the inside surface of the bulb), the other with the collector or anode, which is usually a wire loop or straight wire mounted approximately in the center of the bulb. In use, the anode is kept charged positively so that it will attract and collect the photoelectrons emitted by the light-sensitive surface.

Besides the fluctuations already mentioned, two factors may limit the usefulness of such a cell. The insulation between the two electrodes may not be sufficiently high, or the light-sensitive surface may for some reason or other emit electrons spontaneously.[1] Both effects give rise to a dark current (i.e., a current flows through the cell when the cell is not illuminated), which, while not desirable, may nevertheless remain constant and leave the threshold sensitivity of the cell unimpaired. If, however, the dark current shows fluctuations, these may raise the lower limit of sensitivity to a much higher value than that set by fluctuations in the primary response. This question can be settled experimentally.

While most commercial cells show a relatively large dark current, experiment shows that this is not an intrinsic property of photoelectric cells but is due to accidents of manufacture. One of the very excellent quartz potassium hydride cells made by Dr. Jakob Kunz shows a dark current of about 30 electrons per second when connected with a sensitive vacuum electrometer similar in type to the well-known Hoffmann electrometer. No attempt was made to find short-period fluctuations in this current, for, as will be shown later, we have nothing to fear from variations in currents of this size. The measurement was made with all the important leads and insulators and the anode extension of the cell in an evacuated metal chamber—a precaution which practically eliminated surface leakage

[1] Caesium oxide surfaces show a high thermionic emission at room temperatures. In the case of faint radiation it is an advantage to use these cells at low temperatures.

on the quartz insulation as well as the tendency of the leads to pick up stray ions.

It remains to calculate the fluctuations to be expected in the primary response of a more or less ideal photoelectric cell. We may as well carry out the calculations for a gas cell, as its action is similar to that of the vacuum cell, except that in the gas cell a photoelectron emitted from the light-sensitive surface as it travels to the anode produces a few secondary ions in the gas remaining in the tube. Some of these secondaries produce tertiaries so that, as the cell is ordinarily used, about 10 electrons arrive at the anode for each photoelectron emitted. This ratio is called the "gas-amplification factor" of the cell.

As we do not require very precise data for our calculations, let us start with the following and make reasonable guesses where exact information is lacking. A good quartz potassium hydride cell attached to the 60-inch telescope gives a current of 4.7×10^{-16} amp., or about 3500 electrons per second when the cell receives the light from a 14.5-mag. star. Since this is a gas cell having an amplification of about 10, approximately 350 photoelectrons per second are produced by the light of the star.

From other sources[1] we know that the 60-inch reflector receives about 0.2 erg per second from a 0-mag. star; therefore from a 14.5-mag. star we have $0.2\times1/(6.31\times10^5)$, or approximately 3.2×10^{-7} ergs per second. On the assumption of a mean wave-length of 0.45 μ (maximum sensitivity of the cell is at 0.46 μ), this incident energy amounts to 7.4×10^4 quanta per second. As there are numerous losses in the system and the cell can respond to only a very limited region of the spectrum, let us assume that only 10 per cent of the incident energy can produce photoelectrons. Hence we find that about 1 quantum in 200 produces a photoelectron.

From the theory of probability we know that if e is the chance that an event will happen and $1-e$ the chance that it will fail, then the mean discrepancy in N trials will be

$$\sqrt{Ne(1-e)}\,.$$

[1] Pettit and Nicholson, *Mt. Wilson Contr.*, No. 369; *Astrophysical Journal*, **58**, 279, 1928.

As e in this case is $1/200$, we may ignore e^2 and write for the mean fluctuation in the number of photoelectrons emitted, which we shall call n,

$$\Delta n = \sqrt{Ne} .$$

The number of trials N will of course be equal to the number of quanta considered, and this multiplied by e gives us the number of photoelectrons emitted. Hence

$$\Delta n = \sqrt{n} ,$$

where Δn is the mean fluctuation in the response of the cell when the response n is measured in electrons per second. Actually, since we are dealing with a gas cell, the measured response is not n but μn where μ is the amplification factor. This, however, adds no complication, for Steinke[1] has shown that as long as μ is less than about 50 it may be treated as a constant. Hence, if we call the measured response z, we find, for the mean relative fluctuation in z,

$$\frac{\Delta z}{z} = \frac{\mu\sqrt{n}}{\mu n} = \frac{1}{\sqrt{n}} .$$

Thus far n has represented the average number of photoelectrons emitted per second, but since we could quite as well have averaged over some other time interval, we will now consider n to be the average number of photoelectrons emitted in whatever time interval is used to collect the measured charge z. Obviously the precision of our measurement increases as we increase this interval. Assuming that we are attempting to measure stellar magnitudes with a photoelectric cell attached to the 60-inch reflector, let us see what intervals must be used to obtain data which are accurate say to 1 per cent and to 10 per cent. Table I gives the values for a series of stellar magnitudes necessary if single observations are to fall within these limits of precision.

From this table we see that with the 60-inch reflector it is difficult to obtain data accurate to 1 per cent on objects fainter than the

[1] *Op. cit.*

fifteenth magnitude. It is true that for special purposes one might attempt precise work on fainter objects, but for most astronomical photometry it is not feasible to devote more than a minute to a single measurement. For some purposes fluctuations considerably larger than 1 per cent may be tolerated, but since in most astronomical work on faint objects differences must be observed (sky *plus* star deflections *minus* sky deflections), a precision of 1 per cent becomes almost essential.

TABLE I

Stellar Magnitude	Observing Interval	
	1 Per Cent Fluctuations	10 Per Cent Fluctuations
14	21 sec.	0.2 sec.
15	52	0.5
16	130	1.3
17	310	3.1
18	800	8

It may well be asked if failure does not occur in the instrument which detects the response of the cell before fluctuations in the response itself become serious. Thus far we have assumed that the instrument which measures the cell response is essentially perfect, and in the case of an electrometer of the Hoffmann type this assumption is justified. When used as a charge-measuring instrument it has the required sensitivity, and because of its great stability electrons can be collected over any desired observing interval.

Carnegie Institution of Washington
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ON THE MEASUREMENT AND INTERPRETATION OF FRAUNHOFER LINES[1]

By S. A. KORFF[2]

ABSTRACT

The Fraunhofer D lines of sodium and E_b lines of magnesium were photographed with the 75-foot spectrograph and their contours measured with a microphotometer. These lines were found to have wings agreeing with the radiation damping theory, provided the theoretical contour is fitted at the point where about 0.80 of the light of the continuous background is transmitted—a value higher than that used by most observers. The observed contours show that about 0.25 of the background intensity is transmitted at the centers of the lines. The application of recent experimental data on interaction widening is discussed. It is found that the contribution of interaction to the total width of the lines is small. Quantitative analysis of the solar atmosphere based on the widths of lines produced by scattering is found possible provided the widths are measured in the wings of the lines.

INTRODUCTION

The problem of the contours of the Fraunhofer lines has been examined by a number of investigators. In particular, the D lines of sodium have been studied by A. Unsöld[3] and the E_b lines of magnesium by H. H. Plaskett.[4] Both these observers have obtained contours of the lines and fitted the observed points with a theoretical curve derived from the classical radiation damping theory. They have found that the solar contours depart from the theoretical form both in the center, where theory gives greater blackness than is observed, and in the wings, which are wider than the theory would indicate. The interpretation suggested is that some process other than pure scattering is also at work forming these lines. Plaskett has proposed a model of "combined scattering and absorption" to describe the behavior of the line contours at various points on the solar disk.

If we examine these contours in detail, we find that a slight modification of the usual method of fitting the contours makes it possible to represent the wings by a pure scattering model, although some absorption process is presumably active in the cores. There are

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 459.

[2] National Research Fellow.

[3] *Zeitschrift für Physik*, **46**, 765, 1928.

[4] *Monthly Notices of the Royal Astronomical Society*, **91**, 870, 1931.

several possible interaction processes that would tend to widen the line. One of these, which would also invalidate quantitative analysis based on pure scattering, is a perturbation of the absorbing sodium atom by neighboring sodium atoms. Another is interaction due to atoms of hydrogen and other substances. If such interaction is not too great, the contour of the line remains essentially a "scattering contour," but the width would be greater than radiation damping alone would produce. Only in the absence of interactive effects is quantitative analysis based on pure scattering valid.

FORMATION OF THE LINES

D. H. Menzel[1] estimates the pressure at the base of the reversing layer to be of the order 5×10^{-5} atmospheres. This gives us a value of n, the number of atoms, neutral and ionized, per cubic centimeter through the equation

$$n=n_0\frac{273}{T}\frac{P}{760}, \tag{1}$$

where n_0 is the Loschmidt number, P the pressure in millimeters, and T the absolute temperature, here supposed to be 6000° K. The value of n thus obtained is of the order 6.1×10^{13} atoms per cubic centimeter. If we now take the percentage of neutral sodium atoms from H. N. Russell's[2] estimates as being about 5×10^{-5} of the total n, we have 3.0×10^{9} sodium atoms per cubic centimeter. Korff[3] has shown that interaction between sodium atoms will not set in until the density exceeds 6×10^{13} atoms of sodium per cubic centimeter, and hence we may at once rule out any type of "polarization" widening due to a *Na-Na* interaction.

Consider now the interaction of *Na* with *H*. The "interaction radius" of the *H-Na* combination has been found experimentally[4] to be of the order of 3×10^{-7} cm. We may write t, the mean free time between collisions, approximately equal to

$$t=\frac{1}{n\pi r^2}\sqrt{\frac{m}{3kT}}, \tag{2}$$

[1] *Publications of the Lick Observatory*, **17**, 1, 1931.

[2] *Mt. Wilson Contr.*, No. 383; *Astrophysical Journal*, **70**, 63, 1929.

[3] *Mt. Wilson Contr.*, No. 455; *Astrophysical Journal*, **76**, 124, 1932.

[4] *Ibid.*

where n is the number of atoms per cubic centimeter, r the effective radius of interaction, k the Boltzmann constant, and m the mass of the atom.

Hydrogen is easily the most abundant constituent of the solar atmosphere. Helium, the next most abundant, has but one-third the effective interaction radius in broadening the D lines. Since, as we shall see, the broadening due to hydrogen is just barely sufficient to affect the width, we may safely neglect the broadening due to helium, and, for similar reasons, that produced by all other elements.

If we take n, r, and T of the orders stated, t is found to be about 7.5×10^{-8} sec. On the average, therefore, a hydrogen atom will not collide with a sodium atom within the lifetime of the 2p-state of sodium, which is about 1.5×10^{-8} sec. But it can easily be shown from kinetic-theory considerations that about 1 per cent of an assemblage of atoms will travel a distance of 4.5 mean free paths, and hence come within interaction range and broaden the lines. Because of this, *Na-H* interaction will give a small contribution to the width of the line, the major process being radiation damping.

EXPERIMENTAL CONTOURS

For purposes of checking the theory, contours of the D lines of sodium and the E_b lines of magnesium were obtained with the 75-foot spectrograph on Mount Wilson. The central portion of the solar disk was used throughout. Ilford Special Rapid Panchromatic plates were used and calibrated by a step-slit in place of the regular spectrograph slit. For photographs of the Fraunhofer lines the spectrograph slit was set at 0.02 mm. With all but 1 cm of its length masked off, the spectrum was photographed. The mask was then moved to cover the section just exposed and uncover a new section. The slit was next opened wide and the step-slit superimposed to record the calibrating spectra, which appear on the plate as strips of different densities. The intensities producing the densities were proportional to the openings of the step-slit. Since points on the calibrating spectra corresponding in wave-length to the lines could be selected with accuracy, the photometry was rendered monochromatic. The usual instrumental precautions, such as masking off

portions of the grating, were observed. The plates were developed for 5 minutes at 18° C in X-ray (hydroquinone) developer and brushed with a camel's-hair brush during development. Tracings

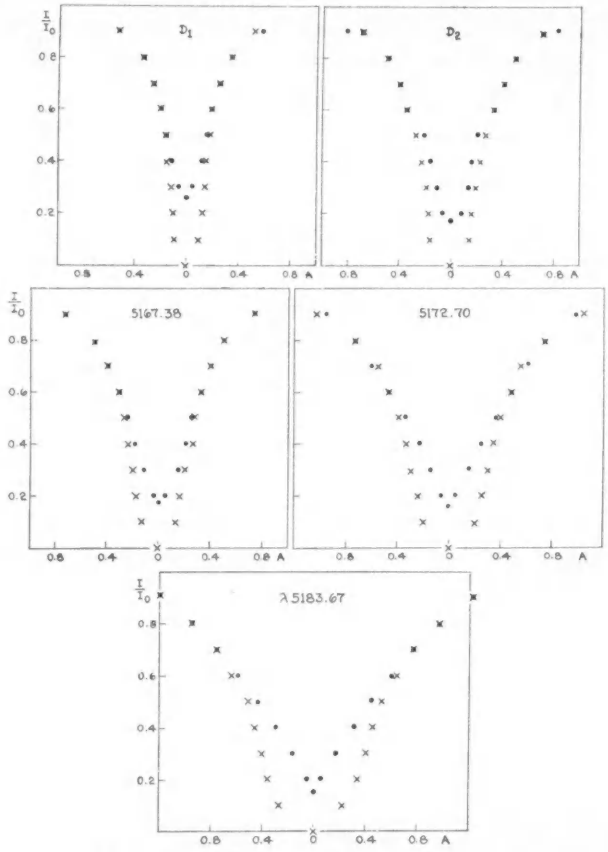

FIG. 1.—Contours of D lines of sodium and E_b lines of magnesium. Points, observed values; crosses, scattering theory adjusted for coincidence at $I/I_0 = 0.8$.

of the plates were made by Miss L. W. Ware on the Koch microphotometer. The methods of reduction were those used in previous work.[1] The contours obtained (Fig. 1) were found to agree well with those of Unsöld[2] and Plaskett.[3]

[1] *Ibid.*

[2] *Op. cit.* [3] *Op. cit.*

Most workers[1] have fitted the observed curves with theoretical radiation damping contours adjusted to agree at the point where $I/I_0 = 0.50$. When this is done, the narrower lines exhibit shoulders agreeing with theory, but the wider lines (such as D and E_b) yield wings about 10 per cent wider than the theory would seem to require. If we adjust the lines to coincide at $I/I_0 = 0.80$ (Fig. 1), the agreement is much improved for the wider lines. For the narrow lines no problem exists, as these agree at all values above 0.50. Below 0.50, scattering theory requires greater blackness than is observed. The lack of agreement at the center is not rendered materially worse by making the adjustment at 0.80. It is suggested, therefore, that 0.80 represents a better point to fit the theoretical curve. Indeed, it was recognized by J. Q. Stewart[2] that there is good theoretical reason for making the fit in the wings rather than deep in the line, since the classical radiation damping theory is especially designed to account for the wings of the lines; nevertheless, some other process must also be at work in forming the cores. The scattering contours are seen to coincide accurately with the observed points in the wings. The agreement is considerably better than many published contours fitted at 0.50. Since interactive effects in the solar case contribute but little to the widths, we may obtain for a given line approximate values of N, the number of atoms in the line of sight, if we measure the widths at 0.80 or 0.75. As Plaskett has pointed out, a combined scattering and absorption model must be used to describe the entire line contour, especially the center, and this model does not yield accurate values of N. But since in the wings single scattering is presumably the cause of the opacity, we may apply the pure scattering formula.

The contour of a line produced by single scattering in a long thin column is given by[3]

$$\log \frac{I}{I_0} = \frac{2\pi e^4 \lambda^2 nzf}{3m^2c^4(\Delta\lambda)^2}, \qquad (3)$$

where e and m are the charge and mass of the electron, z the length of the absorbing column, n the number of atoms per cubic centimeter,

[1] Unsöld, *op. cit.* and Plaskett, *op. cit.*

[2] *Monthly Notices of the Royal Astronomical Society*, **85**, 732, 1925.

[3] Korff, *op. cit.*

$\Delta\lambda$ the wave-length distance from resonance to a point where intensity I has been transmitted. This equation has been modified by Stewart[1] in accordance with Schuster's formula for a foggy atmosphere to take account of multiple scattering in a semi-opaque layer. E. A. Milne[2] later showed that the numerical coefficient in Schuster's formula ought to be slightly changed, and Unsöld[3] indicated a modification relating to the angle. Since the contours determine I/I_0 and $\Delta\lambda$, equation (3) yields values of nz. For the D lines of sodium, f was taken as $2/3$ and $1/3$, while for the E_b magnesium lines it was found that (relative) f's of $5:3:1.4\pm0.3$ gave somewhat better agreement than the theoretical $5:3:1$. The theoretical contours in Figure 1 are drawn for an nz of 1.6×10^{16} atoms of sodium and 8×10^{16} atoms of magnesium. If we assume Russell's value of n sodium atoms per cubic centimeter at the base of the reversing layer, equation (3) indicates that the layer in which the lines are formed has an "equivalent thickness" of 50 km; "equivalent" is taken as meaning a thickness of uniformly the same density as the bottom. The actual thickness will be greater owing to a decrease outward of the density. The rigorous solution will require a complicated outward integration.

These considerations cannot be applied to the hydrogen lines since their very great width is presumably not due to pure scattering. The Doppler width, small for sodium even at solar temperatures, becomes appreciable for hydrogen on account of the small mass. The displacement from exact resonance of the wave-length absorbed by a hydrogen atom moving directly from or toward the photosphere is obviously given by

$$\Delta\lambda=\frac{\lambda}{c}\sqrt{\frac{3kT}{m}}, \tag{4}$$

where $\Delta\lambda$ is the displacement from resonance, λ the wave-length of the line, and m the mass of the hydrogen atom. For $T=6000^\circ$ K, $\Delta\lambda$ for H becomes approximately 0.25 A; for very hot stars it may be as great as 0.5 A. If we allow for the Maxwellian velocity distribu-

[1] *Astrophysical Journal*, **49**, 30, 1924.

[2] *Monthly Notices of the Royal Astronomical Society*, **89**, 3, 1929.

[3] *Op. cit.*, **44**, 796, 1927.

tion and random distribution in the direction of the motion of the absorbing atoms, (4) is readily transformed into the usual Doppler width-equation.

The contribution of Stark effect to the width certainly must also be large. Until we have developed a method for separating this from the Doppler width we shall not be in a position to determine the amount of hydrogen in the sun with any precision.

CENTRAL INTENSITIES

The contours show that about 0.25 of the intensity of the continuous background is transmitted at the center. This result is in agreement with the contours of Plaskett[1] and Unsöld,[2] although Unsöld finds even greater intensities transmitted at the centers of some of the narrower lines. A large fraction of the central transmissions may certainly be attributed to stray light, since contours of laboratory lines having practically zero theoretical central intensity are found[3] to have central transmissions of about 10 per cent. Further, the terrestrial oxygen lines, also theoretically black, are found by R. Woolley[4] to have considerable central intensity. With full sunlight entering the spectrograph, it would be surprising if the scattering did not considerably exceed the laboratory values. J. A. Carroll[5] has shown that one cannot expect to obtain zero central intensities from any grating. He calculates that a grating with 10^5 lines, operating at λ 5000, on a line of half-width 0.1 A and a true central intensity 0.1, will show this line as having a central intensity of 0.22. The grating size and the wave-length, half-width, and the observed central intensity are approximately equal to those in the experimental work outlined above.

Mechanisms have been suggested by Stewart,[6] Pannekoek,[7] and

[1] *Op. cit.*

[2] *Op. cit.*

[3] Korff, *op. cit.*

[4] *Mt. Wilson Contr.*, No. 420; *Astrophysical Journal*, **73**, 185, 1931.

[5] *Monthly Notices of the Royal Astronomical Society*, **88**, 154, 1927.

[6] *Popular Astronomy*, **36**, 345, 1928.

[7] *Proceedings of the Amsterdam Academy*, **34**, 1352, 1931.

others[1] to account for central intensities; but perhaps these should not be criticized until the nature of the problem, from an experimental point of view, is better understood.

The author wishes to thank Miss Ware for making the microphotometer tracings of the Fraunhofer lines studied and Professor J. Q. Stewart for helpful criticisms. He is indebted to the National Research Council for a grant that enabled this investigation to be carried out.

Carnegie Institution of Washington
Mount Wilson Observatory
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[1] Unsöld, *Zeitschrift für Astrophysik*, **4**, 319, 1932.

THE SPECTRUM OF THE A2 DWARF ε SERPENTIS

By W. W. MORGAN and GOLDENA FARNSWORTH

ABSTRACT

Wave-lengths and identifications are given for 244 lines in the spectrum of ε Serpentis between the limits λλ 3997–4629. The elements definitely found to be present are: *H*, *Mg* I, *Mg* II, (*Al* I), *Si* II, *Ca* I, (*Ca* II), *Ti* II, *V* II, *Cr* I, *Cr* II, *Mn* I, *Fe* I, *Fe* II, *Ni* I, *Ni* II, *Sr* II, *Y* II, *Zr* II, *Ba* II, and *La* II. The lines of *Al* I and *Ca* II lie outside of the observed range. In addition to the elements listed, *Sc* II and *Co* I may be present.

The star ε Serpentis (H.D. vis. mag. 3.75; spectrum A2) has a trigonometric parallax of $0''.036 \pm ''.009$ (Allegheny) and a proper motion of $0''.140$ in $65°.5$. The absolute magnitude of the star is $1^m.5$, which places it among the dwarfs. A superficial examination of the spectrum shows that it is a good example of an average A2 dwarf. At least 80 per cent of the A2 stars for which spectrograms are available at Yerkes have practically identical spectra except for different degrees of diffuseness in the quality of the lines.

Three one-prism spectrograms having a scale of 30 A per millimeter at λ 4500 which had been obtained on the fine-grain Eastman Process emulsion were available for study. All of the lines between λλ 3997 and 4629 were measured on one of these plates, while the reality of all lines was checked by reference to the other two spectrograms. In all, 244 lines are included within the limits mentioned. It is probable that a number of lines have been omitted which are almost certainly real, but we do not believe that there are any lines among the ones retained about which there can be doubt as to their reality.

The wave-lengths and identifications of lines are listed in Table I. The system of notation used by Dunham in *The Spectrum of α Persei* has been followed closely. The columns give: (1) the wave-length measured in the star. (2) The stellar intensity, estimated on an arbitrary scale on which the faintest line definitely present is of intensity 1, while the strong *Fe* I line at λ 4045 is of intensity 10. The letters "n" and "N" following the intensities denote a smaller or greater degree of diffuseness. (3) The grade of the identification. Identifica-

TABLE I

WAVE-LENGTHS AND IDENTIFICATIONS OF LINES

λ Star	Int.	Gr.	Cont.	Elem.	λ Lab.	Int. Lab.	λ Star	Int.	Gr.	Cont.	Elem.	λ Lab.	Int. Lab.
3997.48....	5n	A	++	*V* II	.12	(15)	4031.77....	1	A	+++	*La* II	.70	300 III E
			+++	*Fe* I	.40	15 III				+++	*Fe* I	.97	4 V
			++	*Fe* I	8.06	10 III	4033.03....	4	A	+	*Fe* I	2.64	4 III
3998.97....	3	A	+++	*Zr* II	.98	(30)				+++	*Mn* I	3.07	150 I
4005.28....	9	A	+++	*Fe* I	.25	25 II	4034.37....	2	A	+++	*Mn* I	.49	100 I
			+	*V* II	.71	(60)	4035.61....	2	A	+++	*V* II	.62	(40)
4006.47....	1	B	++	*Fe* I	.31	3 V	4041.28....	2n	B	++	*Fe* I	0.63	4 V
			+++	*Fe* I	.63	2 V				++	*Fe* I	1.29	(1)
4007.54....	1	C	+++?	*Fe* I	.27	6 IV				++	*Mn* I	1.37	50 I
4009.65....	2n	B	+++	*Fe* I	.72	10 III	4042.84....	1	A	+++	*La* II	.92	300 IV E
4012.43....	6	A	+++	*Ti* II	.40	(4)	4044.28....	1	A	+++	*Fe* I	3.90	5n IV
4014.02....	1N	B	+	*Fe* I	3.64	(1)				+++	*Fe* I	4.62	6 IV
			+++	*Fe* I	3.82	2 V	4045.83....	10	A	+++	*Fe* I	.82	60 II
			++	*Fe* I	4.54	10 III	4047.27....	1	B	+++	*Fe* I	.32	(1)
4015.53....	2	A	+++	*Ni* II	.50	(1)	4048.75....	4	A	+++	*Zr* II	.68	(25)
4017.15....	1	A	++	*Fe* I	.10	(1)	4050.46....	1	A	+++	*Zr* II	.32	(15)
			+++	*Fe* I	.15	6 III	4052.27....	2	B	++	*Fe* I	1.93	(2)
4018.23....	1	B	++	*Mn* I	.11	20 I				++	*Fe* I	2.31	(1)
			++	*Fe* I	.28	(2)				++	*Fe* I	2.47	(1)
			++	*Zr* II	.38	(10)	4053.81....	3	A	+++	*Ti* II	.84	(3)
4020.45....	1	D	++?	*Fe* I	.49	(1)	4055.09....	2	B	+	*Fe* I	4.83	(1)
4021.79....	3	A	+++	*Fe* I	.87	12 III				++	*Fe* I	4.88	5n V
4023.23....	2	A	+++	*V* II	.38	(50)				++	*Fe* I	5.05	3 V
4024.69....	5n	B	+	*Zr* II	.45	(12)				+	*Mn* I	5.55	20 I
			+++	*Fe* I	.75	6n V	4057.37....	3	A	+	*Fe* I	.36	2 V
			++	*Ti* II	5.13	(2)				+++	*Mg* I	.48	(5)
4028.22....	3	A	+++	*Ti* II	.35	(7)	4058.58....	1	B	+++	*Fe* I	.23	4n IV
4029.62....	1	A	+++	*Fe* I	.64	3n V				+++	*Fe* I	.77	3 IV
			+++	*Zr* II	.68	(20)	4059.81....	1	B	+++	*Fe* I	.73	3 V
4030.62....	6	A	+	*Fe* I	.51	(3) IV	4061.19....	1	C	+++?	*Fe* I	.12	(1)
			+++	*Mn* I	.76	200 I	4062.39....	1	A	+++	*Fe* I	.45	10 III

4063.60	8	A	+	*Fe* I	.30	(2)	4127.86	5n	A	++	*Fe* I	.62	7 IV
			+++	*Fe* I	.60	45 II				++	*Fe* I	.81	3n V
4065.18	1	C	+++	*Fe* I	.40	(1)				+++	*Si* II	8.05	(5)
4067.02	6	A	+	*Fe* I	6.98	6 III	4130.77	4	A	+++	*Si* II	.88	(6)
			+++	*Ni* II	7.04	(3)	4132.11	5	A	+++	*Fe* I	.06	25 II
			+	*Fe* I	7.28	4 III				+	*Fe* I	.91	8 III
4067.93	2	A	+++	*Fe* I	.99	8n III	4134.57	3	A	+	*Fe* I	.34	(1)
4070.78	1	A	+++	*Fe* I	.78	5n III				+	*Fe* I	.43	(1)
4071.73	7	A	+++	*Fe* I	.75	40 II				+++	*Fe* I	.68	12 IV
4073.66	1	A	+++	*Fe* I	.76	4n IV	4137.00	3	A	+++	*Fe* I	.00	7 IV
4074.83	1	A	+++	*Fe* I	.79	5 IV	4140.47	1	E	+++?	⊙ II	.41	(3)
4076.63	1	A	+++	*Fe* I	.64	8n IV	4141.92	1	B	+++	*Fe* I	.86	(1)
4077.74	9	A	+++	*Sr* II	.71	400 II	4143.68	8	A	++	*Fe* I	.42	15 III
4079.51	1	B	++	*Mn* I	.25	12 I				+++	*Fe* I	.87	30 I
			++	*Mn* I	.43	10 I	4145.79	2	D	+++?	*Fe* I	6.07	(2)
			+++	*Fe* I	.85	4 IV	4147.45	2	D	+?	⊙ II?	6.99	(2)
4085.29	2	A	+++	*Fe* I	.01	4 IV				+?	⊙ II?	7.35	(2)
			+++	*Fe* I	.31	4 IV				+++	*Fe* I	7.68	10 III
4086.78	1	A	+++	*La* II	.72	400 III E	4149.14	5	A	+++	*Zr* II	.22	(75)
4090.36	1	A	+++	*Zr* II	.52	(10)				+	*Fe* I	.37	5 V
4101.85	50	A	+++	*Hδ*	.74	(7)	4150.80	1	A	+++	*Zr* II	.97	(10)
4107.56	1	A	+++	*Fe* I	.50	12 III	4152.10	2	B	+++	*La* II	1.95	300 III E
4109.68	1	A	+	*Fe* I	.07	(1)				++	*Fe* I	2.18	4 II A
			+++	*Fe* I	.81	9 IV ?	4154.35	4n	A	++	*Fe* I	3.92	9 IV
4113.09	1	B	+++	*Fe* I	2.98	3n V				++	*Fe* I	4.50	12 III
4114.62	1	B	+++	*Fe* I	.45	5 IV				++	*Fe* I	4.82	9 IV
4118.48	5	A	+++	*Fe* I	.56	15 IV	4156.44	4	B	+++	*Zr* II	.24	(15)
			++	*Co* I	.78	50 II				+++	*Fe* I	.81	12 III
4119.89	1	D	+++?	*Fe* I	0.21	5 IV	4157.82	1	A	+++	*Fe* I	.80	8 IV
4121.53	2	B	+++	*Co* I	.33	60 II	4159.08	2	C	+++	*Fe* I	8.81	5 V
			+++	*Fe* I	.81	5 IV				+++	⊙ II	9.19	(5)
4122.74	3n	A	+	*Fe* I	.52	4 IV	4161.51	4n	B	++	*Zr* II	.20	(20)
			+++	*Fe* II	.67	(*)				++	*Ti* II	.52	(1)
			++	*La* II	3.23	600 III E				++	*Sr* II	.81	30 IV
4124.81	1	A	+++	*Y* II	.95	20 III E	4163.61	4	A	+++	*Ti* II	.65	(40)
4126.16	1	A	+++	*Fe* I	.19	3n IV	4165.53	1	B	+++	*Fe* I	.42	(2)

TABLE I—*Continued*

λ Star	Int.	Gr.	Cont.	Elem.	λ Lab.	Int. Lab.
4167.31	4	A	+++	*Mg* I	.39	10 III
4171.02	2	B	+++	*Fe* I	0.91	5 IV
4172.13	4	A	+++	*Ti* II	1.90	(30)
4173.35	5	A	+++	*Fe* II	.48	(5)
			++	*Ti* II	.55	(1)
4175.69	1	A	+++	*Fe* I	.64	10 III
4177.66	6	A	+++	*Y* II	.61	125 III
4178.86	6n	B	+++	*Fe* II	.87	(8)
4181.85	5	A	+++	*Fe* I	.76	15 III
			+	*Fe* I	2.39	4 IV
4183.5	3NN	B	++	*V* II	3.43	(35)
4185.3			++?	⊙ II	4.00	(4)
			++	*Ti* II	4.33	(0)
			++	*Fe* I	4.90	10 III
4186.80	4	A	++	*Zr* II	.70	(12)
			+++	*Fe* I	7.05	20 III
4187.64	4	A	+++	*Fe* I	.81	20 III
4188.92	1	E	+++?	⊙ II	.74	(4)
4191.59	5	A	+++	*Fe* I	.45	15 III
			+	*Fe* I	.68	(1)
			+	*Ni* II	2.07	(1)
4193.53	1	E	.....	.....	.....	.....
4195.45	3	A	+++	*Fe* I	.34	5 IV
			+	*Fe* I	.62	(2)
4196.47	2	B	+++	*Fe* I	.22	4 IV
			+++	*La* II	.56	300 III
4198.65	7N	A	+++	*Fe* I	.31	20 III
			+++	*Fe* I	9.10	20 III
4200.78	1	B	+++	*Fe* I	.92	3 V
4201.98	5	A	+++	*Fe* I	2.03	30 I
			+	*V* II	2.34	(35)
4203.87	1	B	+++	*Fe* I	.99	10 III
			++	*La* II	4.04	100 V
4205.11	2	B	+	*Y* II	4.69	20 V
			+++	*V* II	5.09	(30)
4207.08	1	A	+++	*Fe* I	.13	4 IV
4208.76	2	B	++	*Fe* I	.61	3 V
			+++	*Zr* II	.99	(30)
4210.28	3	A	+++	*Fe* I	.36	15 III
4211.83	2	A	+++	*Zr* II	.88	(12)
4213.69	2	A	+++	*Fe* I	.65	5 IV
4215.48	9	A	+++	*Sr* II	.52	300 II
4217.47	2	B	+++	*Fe* I	.56	7 IV
			+	*La* II	.56	80 V
4219.34	3	A	+++	*Fe* I	.36	12 IV
4220.49	1	B	+++	*Fe* I	.35	4 IV
4222.33	3	A	+++	*Fe* I	.23	12 III
4224.24	2	A	+++	*Fe* I	.18	6 IV
			++	*Fe* I	.51	3 IV
4225.68	1	B	++	*V* II	.23	(20)
			+++	*Fe* I	.46	6 IV
			++	*Fe* I	.96	3 IV
4227.16	6n	A	+++	*Ca* I	6.73	500 I
			+++	*Fe* I	7.44	30 III
4233.26	9	A	+++	*Fe* II	.16	(10)
			++	*Fe* I	.61	18 III
4235.85	6	A	++	*Y* II	.71	40 IV
			+++	*Fe* I	.95	25 III
4238.48	2	A	+++	*La* II	.40	400 III
			+++	*Fe* I	.82	10 IV
4239.94	1	B	+++	*Fe* I	.85	3 III
4242.30	4	A	+++	*Cr* II	.37	(5)
4245.13	1	B	++	*Ni* II	4.80	(1)
			+++	*Fe* I	5.26	6 III
4247.34	3	B	+	*Sc* II	6.84	75 III
			+++	*Fe* I	7.44	12 III

4250.51....	6n	A	+++	*Fe* I	.13	25 III	4302.01 }	3	A	+++	*Ti* II	1.93	(15)
			+++	*Fe* I	.79	25 II				+	*Ca* I	2.53	60 I
4252.69....	1	A	+++	*Cr* II	.65	(1)	4303.21 } ..	4	A	+++	*Fe* II	3.18	(4)
4254.38....	4	A	+++	*Cr* I	.34	500 II	4305.41....	3	B	++	*Fe* I	.46	3 IV
4258.19....	3	B	+++	*Zr* II	.05	(12)				+++	*Sr* II	.46	40 III
			+++	*Fe* II	.16	(*)	4307.89....	6	A	++	*Ti* II	.86	(40)
4260.39....	5	A	+++	*Fe* I	.49	35 III				+++	*Fe* I	.91	35 II
4261.87....	2	A	+++	*Cr* II	.90	(2)	4309.53....	4	A	+	*Fe* I	.38	4 IV
4263.98....	1	B	+++	*La* II	.59	100 VE				+++	*Y* II	.61	125 III
			+++	*Fe* I	4.21	(2)	4312.86....	3	A	+++	*Ti* II	.87	(35)
4267.98....	1	B	+++	*Fe* I	.83	5 IV	4314.96....	6n	B	+	*Sc* II	.09	100 III
4269.19....	1	B	+++	*Cr* II	.30	(1)				+++	*Ti* II	.98	(40)
			++	*La* II	.50	150 VE				++	*Fe* I	5.09	10 III
4271.58....	7n	A	++	*Fe* I	.17	20 III	4316.81....	1	A	+++	*Ti* II	.81	(1)
			+++	*Fe* I	.77	35 II	4318.74....	1	A	+++	*Ca* I	.65	45 I
4273.35....	2	A	+++	*Fe* II	.31	(1)	4320.92....	2	B	+	*Sc* II	.73	75 III
4275.05....	3n	A	+++	*Cr* I	4.79	400 II				+++	*Ti* II	.95	(1)
			++	*Cr* II	5.56	(1)	4325.79....	7	A	+++	*Fe* I	.77	35 II
4278.04....	1	A	+++	*Fe* II	.13	(1)	4330.67....	2	B	++	*Ti* II	.26	(0)
			+	*Fe* I	.23	(2)				+++	*Ti* II	.71	(0)
4280.18....	1	E	.....	.....	.....	.....	4333.89....	1	A	+++	*La* II	.77	600 III
4282.46....	4	A	+++	*Fe* I	.41	12 III	4337.90....	5	A	+	*Fe* I	.05	10 II
4284.18....	1	A	+++	*Cr* II	.20	(2)				+++	*Ti* II	.92	(50)
4287.92....	2	A	+++	*Ti* II	.89	(2)	4340.47....	50	A	+++	*Hγ*	.47	(8)
			+	*Ni* I	8.01	15 V	4351.86....	7	B	+++	*Fe* II	.77	(10)
4289.96....	7	B	++	*Cr* I	.73	350 II				+	*Cr* I	.77	60 I
			+++	*Ti* II	0.22	(50)				++	*Mg* I	.94	30 IV
4292.14....	1	B	+++	*Fe* I	.13	(pred)	4358.64....	1	A	+++	*Y* II	.74	50 III
			+++	*Fe* I	.29	(1)	4362.39....	1	B	+++	*Ni* II	.10	(1)
4294.14....	5	A	+++	*Ti* II	.10	(40)	4367.58....	2	A	+++	*Fe* I	.58	5 IV
			++	*Fe* I	.13	15 II				+++	*Ti* II	.66	(15)
4296.55....	4	A	+	*La* II	.06	200 IV	4369.56....	3	A	+++	*Fe* II	.41	(*)
			+++	*Fe* II	.56	(3)				+++	*Fe* I	.78	7 III
4299.70....	5n	A	++	*Fe* I	.25	18 III	4374.88....	5	A	+	*Ti* II	.83	(1)
			+++	*Ti* II	0.05	(60)				+++	*Y* II	.96	300 III

TABLE I—*Continued*

λ Star	Int.	Gr.	Cont.	Elem.	λ Lab.	Int. Lab.
4375.85	1	A	+++	*Fe* I	.93	9 I
4379.58	1	B	++	*V* I	.24	150 II
			+++	*Zr* II	.78	(9)
4383.64	5	A	+++	*Fe* I	.55	45 II
4385.38	4	A	+++	*Fe* II	.39	(5)
4386.74	1	A	+++	*Ti* II	.86	(10)
4388.51	2	B	++	*Fe* I	7.90	3 IV
			+++	*Fe* I	8.42	4 IV
			+	*Fe* I	9.21	2 II A
4390.78	3n	B	++	*Mg* II	.59	(10)
			++	*Fe* I	.96	4 IV
			+++	*Ti* II	1.02	(tr.)
4395.13	5	B	+	*Ti* II	4.06	(2)
			+++	*Ti* II	5.04	(60)
			+	*Ti* II	5.85	(2)
4398.07	3	A	+++	*Y* II	.03	100 III
			+	*Ti* II	.32	(1)
4399.80	3	A	+++	*Ti* II	.77	(35)
4401.47	3	A	+++	*Ni* I	.55	30 III
4404.85	5	A	+++	*Fe* I	.75	30 II
4408.50	2N	B	++	*Ti* II	7.68	(1)
			++	*Fe* I	7.72	5 III ?
			++	*Fe* I	8.42	6 III ?
			++	*Ti* II	9.24	(tr.)
			++	*Ti* II	9.54	(tr.)
4410.99	1	A	+++	*Ti* II	1.08	(15)
4415.07	5	A	+++	*Fe* I	.13	20 II
4416.85	4	A	+++	*Fe* II	.81	(8)
4417.72	3	A	+++	*Ti* II	.72	(40)
4422.50	3	A	+	*Ti* II	1.95	(1)
			+	*Fe* I	2.57	6 III
			+++	*Y* II	2.61	80 III
4425.59	1	A	+++	*Ca* I	.43	50 I
4427.42	1	A	+++	*Fe* I	.31	10 I
4430.30	2n	A	+++	*La* II	9.91	500 III
			+++	*Fe* I	0.62	6 III
4433.44	1	B	+++	*Fe* I	.22	3 IV
			++	*Mg* II	.99	(8)
4435.21	1	A	+++	*Ca* I	4.95	60 I
			+	*Fe* I	5.15	2 II A
			++	*Ca* I	5.67	40 I
4442.22	1	A	++	*Ti* II	1.72	(pred.)
			+++	*Fe* I	2.35	12 III
4443.74	5n	B	++	*Zr* II	2.99	(25)
			+	*Fe* I	3.20	7 III
			+++	*Ti* II	3.80	(50)
			++	*Ti* II	4.56	(1)
4447.68	2	A	+++	*Fe* I	.73	9 III
4450.42	2	A	+++	*Ti* II	.49	(10)
4454.79	3	B	++	*Fe* I	.39	5 III
			++	*Ca* I	.77	80 I
			++	*Zr* II	.80	(10)
4459.13	3	A	+++	*Ni* I	.05	20 III
			++	*Fe* I	.13	10 III
4461.71	3	B	++	*Zr* II	.22	(10)
			+++	*Fe* I	.66	8 I
			++	*Fe* I	2.00	(3)
			+	*Mn* I	2.03	20 III
4464.37	2	A	+++	*Ti* II	.50	(1)
4466.68	2	A	+++	*Fe* I	.56	12 II
4468.58	4	A	+++	*Ti* II	.49	(50)
			+	*Ti* II	9.15	(tr.)
4470.64	2	A	+++	*Ni* I	.49	15 III
			+++	*Ti* II	.86	(tr.)

4472.79....	2	A	+++	*Fe* II	.93	(*)	4555.91....	5	A	+	*Cr* II	.09	(10)
4476.18....	3	A	+++	*Fe* I	.02	10 III				+++	*Fe* II	.90	(15)
			?	*Fe* I	.08	(−)	4558.59....	4	A	+	*La* II	.48	250 III
4481.21....	10	A	+++	*Mg* II	.13	(100)				+++	*Cr* II	.66	(20)
			+++	*Mg* II	.33	(100)	4563.77....	4	A	+++	*Ti* II	.76	(30)
4484.05....	1	B	+++	*Fe* I	.24	4 IV	4565.95....	1n	B	+	*Co* I	.60	15 III
4485.78....	1	B	+++	*Fe* I	.68	(3)				++	*Fe* I	.68	(2)
4489.18....	3n	B	++	*Ti* II	8.32	(15)				++	*Fe* I	6.52	(2)
			+++	*Fe* II	9.21	(10)				+	*Fe* I	6.88	(1)
4491.36....	4	A	+++	*Fe* II	.41	(8)	4568.44....	1	A	+++	*Ti* II	.31	(1)
4494.47....	3	A	+	*Zr* II	.41	(8)	4571.88....	5	A	+++	*Ti* II	.97	(50)
			+++	*Fe* I	.57	12 III	4576.43....	3	A	+++	*Fe* II	.31	(10)
4496.81....	1	A	+++	*Zr* II	.96	(15)	4580.23....	2	B	++	*La* II	.08	100 V
4501.29....	4	A	+++	*Ti* II	.27	(40)				+++	*Ti* II	.47	(1)
4508.28....	5	A	+++	*Fe* II	.29	(15)	4583.93....	6n	A	+	*Fe* II	2.84	(*)
4515.26....	4	A	+++	*Fe* II	.34	(15)				+	*Ti* II	3.45	(1)
4517.76....	1	B	+++	*Fe* I	.53	(3)				+++	*Fe* II	3.84	(30)
4520.21....	4	A	+++	*Fe* II	.24	(8)	4586.11....	1	A	+++	*Ca* I	5.87	50 II
4522.52....	5	A	+	*La* II	.39	500 III	4588.27....	3	A	+++	*Cr* II	.21	(20)
			+++	*Fe* II	.64	(10)	4590.07....	1	A	+++	*Ti* II	9.96	(2)
4524.99....	2	A	++	*Ti* II	.73	(1)?	4592.14....	3	B	+++	*Cr* II	.06	(4)
			+++	*Fe* I	5.15	5 IV				++	*Ni* I	.53	10 III
4528.65....	4	A	+++	*Fe* I	.62	18 II				+	*Fe* I	.66	5 I
4531.17....	1	A	++	*Co* I	0.99	30 II	4595.86....	1	A	+++	*Fe* II	.70	(*)
			+++	*Fe* I	1.16	8 II	4605.19....	1	A	+++	*Ni* I	4.99	12 III
4533.97....	5	A	+++	*Ti* II	.97	(30)	4611.48....	1	A	+++	*Fe* I	.29	5 III
			+	*Fe* II	.17	(*)	4613.22....	1	A	+++	*Fe* I	.22	2 V
4541.62....	2	A	+++	*Fe* II	.52	(*)				+++	*La* II	.40	200 V
4544.52....	1	B	+++	*Ti* II	.02	(tr.)	4616.60....	2	A	+++	*Cr* II	.72	(3)
			+++	*Ti* II	5.14	(tr.)	4618.95....	4	A	+++	*Cr* II	.82	(10)
4549.58....	9	A	+++	*Fe* II	.48	(20)				+	*Fe* I	9.30	3 IV
			+++	*Ti* II	.62	(60)	4620.60....	2	A	+++	*Fe* II	.52	(*)
4554.13....	5	A	+	*Zr* II	3.96	(12)	4629.42....	6	A	+++	*Fe* II	.33	(20)
			+++	*Ba* II	4.04	1000 II							

NOTES TO TABLE I

4183.5–4185.3. The wave-lengths given are the violet and red edges of a very broad, blended group of lines.

4227.16. The two components of this blend are resolved on two-prism plates of μ Orionis (A2). In the spectrum of the latter star *Ca* I is possibly slightly stronger than *Fe* I.

4302.01–4303.21. The lines are very close together and merge slightly into each other. The *Ca* I contributor is probably lost in the overlapping of the two strong lines.

tions of the highest class are graded "A," while a completely unknown line is graded "E." The intermediate letters represent varying degrees of completeness in the identification. Grades A and B can be considered satisfactory; Grade C represents a line only partially accounted for, or in which there is some question as to the proper identification; and Grade D a line for which only a very doubtful identification can be made. (4) The relative contribution of each element to the observed stellar line. The different amounts of contribution are denoted by:

\+ Slight but probably sensible contributor
\++ Important contributor, but <50 per cent
\+++ Contributor $\geqq 50$ per cent

The two lowest grades listed by Dunham which denote no sensible contribution have not been listed unless they are believed to affect the intensity of the stellar line sensibly. (5) The element for which the relative contribution is given in column 4. (6) The laboratory wave-length of the line. (7) The laboratory intensity and temperature class of the line. All intensities other than King's are parenthesized.

THE ELEMENTS PRESENT IN ϵ SERPENTIS

H. The hydrogen lines are almost at their maximum intensity. They are approximately of the same intensity as in Sirius (A0).

Mg I. The singlets at λλ 4057, 4167, and 4351 are well marked. Magnesium is only a minor contributor to the blend at λ 4351, but λ 4167 is probably entirely unblended.

Mg II. λ 4481 is one of the strongest metallic lines in the spectrum. It is possible that several other fainter lines of *Mg* II contribute sensibly to blends.

Al I. The strong ultimate doublet is out of the range included, but the lines are present on plates extending sufficiently far into the violet.

Si II. The doublet at λλ 4128 and 4130 is present. λ 4128 is blended with two lines of *Fe* I, but the other component is unblended and is a rather strong line.

Ca I. The ultimate line at λ 4227 is present but is blended with a strong *Fe* I line. Lines of intensity 50 or stronger on King's scale are present.

Ca II. The *H* and *K* lines are out of the range considered, but are very strong.

Sc II. The presence of *Sc* II is uncertain. All of its strong lines are blended in the star.

Ti II. Practically all of the lines of ionized titanium are present.

V II. The lines which are sensibly unblended are at λλ 4023, 4035, and 4205. Ionized vanadium seems definitely present.

Cr I. The ultimate group at λλ 4254, 4275, and 4289 is present. The first member is unblended, while the last two are hopelessly blended with *Cr* II and *Ti* II, respectively. It is possible that a few other strong *Cr* I lines contribute sensibly to blends.

Cr II. All but the weakest of the lines of *Cr* II are present. The strongest lines are of moderate intensity.

Mn I. The strong ultimate lines at λλ 4030, 4033, and 4034 are well marked. The first two lines are blended slightly with *Fe* I. A number of weaker *Mn* I lines probably contribute to blends.

Fe I. There are far more lines of neutral iron than of any other element. Lines of intensity 3 on Rowland's scale in the sun are, on the average, of intensity 1 in the star.

Fe II. All of the lines classified in the observed range are present. Lines marked with an asterisk in the intensity column are predicted lines which were ascribed to iron due to their behavior in the spectra of sunspots as compared with the solar disc.

Co I. The two strongest lines at λλ 4118 and 4121 probably contribute sensibly to blends in the star.

Ni I. The strongest line of *Ni* I at λ 4401 is of moderate intensity and seems to be sensibly unblended. Several other lines are present; but they are, for the most part, blended.

Ni II. All of the classified lines in the region are probably present. The strongest line at λ 4067 is disturbed somewhat by neutral iron, but the line at λ 4015 is unblended.

Sr II. The ultimate doublet at λλ 4077 and 4215 is very strong. Several subordinate lines probably contribute sensibly to blends.

Y II. The strong line at λ 4177 is of intensity 6 in the star and is apparently unblended. The lines at λλ 4309, 4374, and 4398 are all blended, but in each case yttrium is the principal contributor.

Zr II. The strongest line in the observed region at λ 4149 is slight-

ly blended. It is of intensity 5. A number of unblended lines are present, the strongest being at λ 4048.

Ba II. The ultimate line at λ 4554 is blended with *Zr* II, but the strength of the line leaves no doubt that *Ba* II is the principal contributor.

La II. There are three stellar lines of intensity 1 which are probably due entirely to *La* II. A number of other lines contribute to blends.

There is little evidence for the presence of any of the rare earths. This is in striking contrast to certain of the peculiar early A-type stars in which *Eu* II is strong and in which the presence of other elements of the rare earth group has been suspected. The line at λ 4205 which coincides in position with the strongest line of *Eu* II is apparently due to *V* II, slightly blended with a *Y* II line located in the laboratory half an angstrom to the violet.

There are four lines, all of intensity 1, for which no identification of any sort could be made. They are listed in Table II.

TABLE II

UNIDENTIFIED LINES

λ Star	Int.	λ ⊙
4140.47	1	⊙ II? .41 (3)
4188.92	1	⊙ II .74 (4)
4193.53	1	
4280.18	1	

The first two lines coincide in position with two well-marked unknown solar lines probably due to an enhanced element. The second line was observed by Dunham in α Persei.

Three works have proved indispensable in the identification of the lines in the spectrum of ε Serpentis. They are *The Revision of Rowland's Preliminary Table of Solar Wave-lengths*, by the Mount Wilson solar observers, *A Study of the Solar Chromosphere* by D. H. Menzel, and *The Spectrum of α Persei* by T. Dunham, Jr. A number of other publications have also been consulted.

YERKES OBSERVATORY
WILLIAMS BAY, WISCONSIN
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ON THE ABSORPTION LINES OF HYDROGEN IN Be STARS

By OTTO STRUVE

ABSTRACT

Contours of the absorption borders on the edges of the bright hydrogen lines $H\beta$ and $H\gamma$ in 14 Be stars are given. Comparison with the contours of the same lines in ordinary dark-line B stars of the same spectral subdivisions shows that they are practically identical. A very slight systematic widening of the absorption borders in the Be stars may be due either to axial rotation or to individual differences between separate stars. The similarity of the contours for stars of classes Be and B is in agreement with the hypothesis that bright lines originate above the reversing layers of the stars, and that on the spectrograms they are superposed over normal absorption lines.

In the spectra of Be stars the bright lines of hydrogen are usually superposed over wide and diffuse absorption lines. Since in most stars the absorption wings are considerably broader than the emission lines, they can be seen on the photographs and on the microphotometric tracings as depressions in the continuous spectrum appearing on both sides of the bright lines. In earlier work[1] I have assumed that the contours of these absorption lines are essentially similar to those of ordinary dark-line B stars. In fact, the total intensities of the bright lines were determined by subtracting from the measured intensity at each point the intensity extrapolated from the absorption wings toward the centers of the lines.

It is important to test this point by direct observation since it has an obvious bearing upon the interpretation of the bright lines. I have suggested in several papers[2] that the emission lines probably originate in a nebulous envelope which may be at a great distance from the reversing layer, where the absorption lines are produced. I have also pointed out that emission-line B stars usually have shallow and broad lines of helium, magnesium, etc., suggestive of rapid axial rotation. According to this hypothesis the contours of all absorption lines should be independent of the bright lines and should resemble

[1] Struve and Schwede, *Physical Review*, **38**, 1195, 1931; Struve, *Zeitschrift für Astrophysik*, **4**, 177, 1932.

[2] Struve, *Astrophysical Journal*, **73**, 94, 1931; Struve and Swings, *ibid.*, **75**, 161, 1932; Struve and Schwede, *Physical Review*, **38**, 1195, 1931; Struve, *Zeitschrift für Astrophysik*, **4**, 177, 1932; *Die Sterne*, **12**, 1, 1932.

those of ordinary dark-line stars having rapid axial rotation. That this is the case for the fainter lines, such as helium, magnesium, etc., is apparent, upon a direct examination of the spectrograms. But these lines are not ordinarily complicated by emission, and the test is therefore not conclusive. In the following pages I shall show that the wings of the hydrogen absorption lines in Be stars are similar to those of ordinary dark-line stars of corresponding spectral class. While this is not a sufficient proof for the rotational interpretation

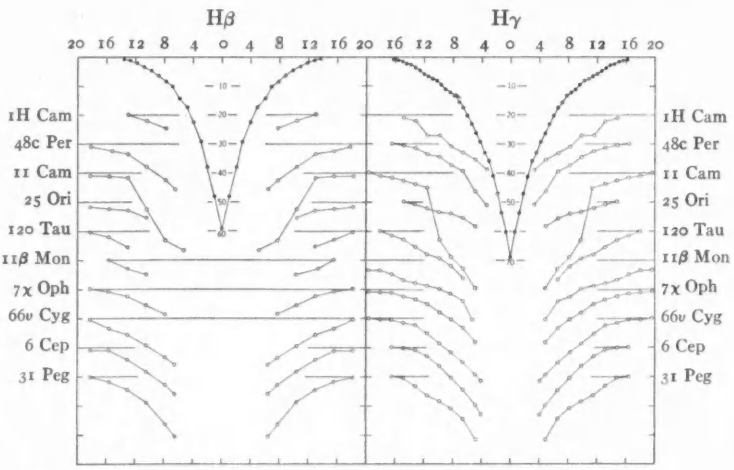

FIG. 1.—Contours of hydrogen absorption lines in B3 stars. Filled circles represent the average dark-line star, open circles represent various emission line stars.

of the emission-line contours, it is a necessary condition, and its fulfilment will add greatly to the conviction that the two types of lines—emission and absorption—do not originate in the same layer of gas, but are merely superposed on the plate.

Measures of the absorption borders of the Be stars were made on the tracings obtained by me in collaboration with Mr. H. F. Schwede.[1] The results for $H\beta$ and $H\gamma$ are shown in Figures 1 and 2. The complete contour at the top of the drawing is the mean for each spectral subdivision as given by C. T. Elvey[2] in his study of the absorption lines of hydrogen in representative stars of various spec-

[1] *Loc. cit.*

[2] *Astrophysical Journal*, **71**, 191, 1930. I am indebted to Dr. Elvey for the use of his measurements which have not been published *in extenso*.

tral classes. There are no Be stars among those measured by Elvey, and his contours are therefore representative for the ordinary dark-line stars. The dispersion used in his work was that of three prisms, while my spectrograms were all taken with a single prism. The methods of measurement and reduction were the same. The absorption wings of the Be stars are shown below each complete contour. In several cases I have combined in one curve the results from several spectrograms of the same star. Each contour repre-

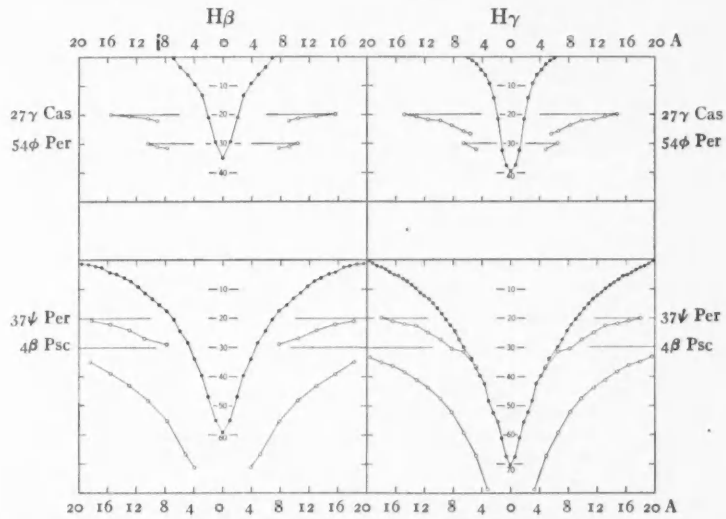

FIG. 2.—Contours of hydrogen absorption lines in Bo stars (top) and in B5 stars (bottom). Filled circles represent the average dark-line star; open circles represent various emission line stars.

sents the wing from the outer edge where it merges with the continuous spectrum, inward as far as the beginning of the emission line. It is broken off at this point, leaving a gap in the curve where the bright line overlaps the absorption line. Right and left sides of the wings have been averaged in order to smooth out accidental errors. Each division in the abscissa corresponds to 4 A, and each division in the ordinate represents 10 per cent of the intensity of the continuous spectrum. The first Be contour on each diagram is placed 2 units (20 per cent) below the contour of the dark-line star, and each following curve is dropped 1 unit (10 per cent).

The contours for the Be stars (with the bright lines left out) show a surprising similarity to those for the dark-line stars. There is possibly a very slight tendency for the Be stars to have the wider wings, but I believe that this difference is so small that it may be attributed to the normal dispersion in line widths within any given spectral subdivision. Elvey's measurements have, in fact, shown that this dispersion may be quite appreciable. If real, the slight difference in width (which is on the average only about an angstrom or two) is in harmony with the rotational hypothesis.

The two Boe stars have appreciably wider hydrogen lines than the corresponding dark-line star. This is probably caused, in part, by rotational broadening, which is also confirmed by the unusually shallow lines of helium in γ Cass. and φ Pers. For classes B3 and B5 the differences between the dark-line stars and the emission-line stars are quite small. There is a general increase in width as we pass from subdivision Bo to B5.

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
May 29, 1932

THE PERIOD OF 12 α^2 CANUM VENATICORUM

By GOLDENA FARNSWORTH

ABSTRACT

From a study made of series of spectrograms taken at several observatories during the years 1913–1932, the period of 12 α^2 Canum Venaticorum, 5.46939 days, was found to be constant within the errors of measurement.

A study of the period of 12 α^2 Canum Venaticorum was made from series of spectrograms taken at the Michigan, Dearborn, and Yerkes observatories. Visual estimates of the intensity of the spectral lines λλ 4130, 4132, 4201, 4205, and 4233 were made on all of the plates.

TABLE I

INTENSITY MAXIMA

SERIES	NUMBER OF PLATES	OBSERVED DATE	COMPUTED DATE	O−C
		Julian Days, Old G.M.T.		
Belopolsky, 1913		2419869.650	2419869.720	−0.070
Markov, 1913		2419908.010	2419908.005	+ .005
Michigan, 1913	36	2419924.495	2419924.414	+ .081
Michigan, 1913, 1917	32	2420197.877	2420197.883	− .006
Markov, 1914		2420274.533	2420274.455	+ .078
Markov, 1919–1920		2422352.923	2422352.823	+ .100
Dearborn, 1928	20	2425257.112	2425257.069	+ .043
Dearborn, 1928–1929	40	2425579.804	2425579.763	+ .041
Yerkes, 1931	34	2426356.371	2426356.417	− .046
Yerkes, 1932	14	2426777.537	2426777.560	−0.023

Using the period of 5.4695 days, graphs were made for each line showing the variation of the intensity with phase. The dates of the observed maxima as recorded in Table I are the average results obtained for these five lines, using the phase of maximum intensity for λλ 4130, 4132, and 4205 and the phase of minimum intensity for λ 4201 and λ 4233. The maximum observed by A. Belopolsky[1] was obtained by making a graph of his data on the spectral line λ 4130, using the same period as that given above. A. Markov[2] gave the

[1] *Astronomische Nachrichten*, **196**, 6, 1913.

[2] *The Spectrum of 12 α^2 Canum Venaticorum*, Leningrad, 1926.

observed maximum recorded for his 1914 series of spectrograms. Since he did not give the maxima for his 1913 and 1919–1920 series, it was necessary to compute these, using his period of 5.4705 days.

A period of 5.46939 days was used to compute the dates of maximum intensity. The following elements were found to fit the complete series of maxima best: *Eu* II maximum = J.D. 2419869.720 + 5.46939*E*. These results, together with the errors between the observed and computed dates, are given in Table I. There is at present no evidence of a variation in the period as the values of (O − C) are scattered and within the error of measurement.

I wish to express my thanks to Dr. H. D. Curtis, director of the University of Michigan Observatory, and to Dr. O. J. Lee, director of the Dearborn Observatory, for placing at my disposal the spectrograms taken at their observatories.

YERKES OBSERVATORY
July 1932

FOUR A- AND F-TYPE STARS WHOSE SPECTRA CONTAIN VARIABLE ABSORPTION LINES

By W. W. MORGAN

ABSTRACT

The stars 49 Cancri, ω Ophiuchi, 73 Draconis, and γ Equulei contain variable absorption lines in their spectra.

The four stars listed in Table I have recently been found to contain absorption lines in their spectra which vary in intensity.

The *Henry Draper Catalogue* classifies 49 Cancri as peculiar because of the strength of the *Si* II doublet λ 4128 and λ 4131. On Yerkes spectrograms λ 4205 is strong when λ 4215 is faint and is practically absent when λ 4215 is at maximum.

TABLE I

Star	Mag.	Spec. (H.D.)	Position (1900)		Variable Lines
49 Cancri.....	5.6	Aop	8^h39^m	10°27′	*Eu* II 4205, *Sr* II 4215
ω Ophiuchi....	4.6	Fo	16 26	21 15	*Sr* II 4215
73 Draconis....	5.2	A2p	20 33	74 37	*Eu* II 4205
γ Equulei.....	4.8	Fop	21 05	9 44	*Cr* II 4558

Sr II 4077 is mentioned as being strong in ω Ophiuchi in the *Henry Draper Catalogue*, and the spectrum is said to resemble that of α Circini. The line λ 4077 is rather far to the violet to be best seen on the Yerkes plates of this star, but the other member of the *Sr* II doublet at λ 4215 varies greatly in intensity. The variation is rapid, as the line was at minimum on July 13, 1932, at maximum on July 15, and at minimum again on July 19. It was also at maximum on March 12, 1932.

The unusual strength of λλ 4077, 4128, 4131, and several other metallic lines in the spectrum of 73 Draconis is mentioned in the *Henry Draper Catalogue*. The variation in intensity of λ 4205 takes place probably in a rather long period.

The spectrum of γ Equulei was classed as peculiar by the Henry Draper observers because of the strength of *Sr* II 4077.

The line *Cr* II 4558 varies from an intensity equal to that of the well-marked line at λ 4549 until it is among the weakest lines in the spectrum.

All the foregoing stars are being further observed for the purpose of determining the periods and other characteristics of the variable lines.

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
July 20, 1932

A NOTE ON THE OCCURRENCE OF *O*III IN STELLAR SPECTRA

By ROY K. MARSHALL

ABSTRACT

Single-prism spectrograms taken at Ann Arbor show *many lines in the spectra of early class stars which can be assigned to* O III. The *strongest lines* due to this atom *are in the near ultra-violet.* A *table* of measured wave-lengths *of lines attributed to* O III *is given.*

In the course of a detailed study of the spectra of eleven stars of classes O and B (to appear as a part of the *Publications of the Observatory of the University of Michigan*), the near ultra-violet region was examined and measured as far as was permitted by the transmission curve of the glass single-prism spectrograph on the $37\frac{1}{2}$-inch Ann Arbor reflector. The final table of wave-lengths covers the region from 3587 to 5048 A, and the number of identifications is very satisfactory. The high quality of the plates, owing to the use of Eastman Process emulsion, rendered measurable many faint lines which are certainly present and which might otherwise have been missed.

In Otto Struve's recent paper of a similar nature,[1] four identifications with *O*III are cited, with lines at 3961.59 (8), 4073.90 (0), 4081.10 (1), and 4379.55 (3), the figures in parentheses being the laboratory intensities. The first of these lines is blended with a line of *S*III at 3961.56 (3), the second one is very weak, the third only slightly stronger, and the fourth is blended with a very strong line of *N*III at 4379.09 (10). Only the first of these four identifications can be said to be at all certain, in view of these difficulties of blending and weakness of lines.

In the region of wave-length shorter than 3800 A, the best lines of *O*III occur, and the results of the present investigation show their existence beyond any doubt. In Table I are given the identifications with *O*III in the region 3600–3800 A which appear in the final list of wave-lengths in the forthcoming paper. In the first column appear

[1] *Astrophysical Journal*, **74**, 277, 1931.

the mean international wave-lengths, in the next four the measured wave-lengths in 10 Lacertae (O9), κ Cassiopeiae (Bo), β Canis Majoris (B1), and β Cephei (B1), the four hottest stars studied in this region, accompanied by the stellar intensities (estimated on a purely arbitrary basis, in which a value of 1 represents the faintest measur-

TABLE I

Mean λ	10 Lac O9	κ Cas Bo	β CMa B1	β Cep B1	Identifications*
3705.01....	5.01 (6)	4.72 (3)	5.02 (6)	5.07 (6)	*He*I 5.003 (3); *He*I 5.139 (1); OIII 4.73 (3); *H*ξ 3.855
3707.40....	7.40 (3)	.....	.....	.....	OIII 7.24 (6)
3709.70....	9.79 (3)	.....	9.53 (1)	.....	OIII 9.52 (2); SIII 9.40 (3)
3712.75....	2.98 (4)	2.33 (3)	2.83 (4)	2.79 (7)	OII 2.75 (7); *H*ν 1.973; OIII 2.48 (2)
3715.14....	5.14 (4)	.....	.....	.....	OIII 5.08 (6)
3729.09....	9.09 (2)	.....	.....	.....	OII 9.34 (2); OIII 8.70 (1); OIII 9.70 (1)
3754.72....	4.79 (8)	4.50 (2)	.....	.....	OIII 4.67 (7); NIII 4.62 (6)
3757.22....	7.29 (7)	7.14 (2)	7.38 (2)	.....	OIII 7.21 (5)
3759.82....	9.89 (10)	9.41 (1)	9.91 (2)	9.95 (1)	OIII 9.87 (9)
3774.10....	4.10 (3)	.....	.....	.....	OIII 4.00 (6); SIII 4.64 (0)
3791.39....	1.36 (4)	.....	1.37 (4)	1.44 (5)	SiIII 1.41 (3); OIII 1.26 (6)

* The sources for the laboratory wave-lengths and intensities are as follows:
H: W. E. Curtis, *Proceedings of the Royal Society*, A, **90**, 605, 1914.
*He*I: A. Fowler, *Report on Series in Line Spectra*, pp. 93, 94, 1922.
NIII: L. J. Freeman, *Proceedings of the Royal Society*, A, **121**, 318, 1928.
OII: A. Fowler, *ibid.*, **110**, 476, 1926.
OIII: *Ibid.*, **117**, 317, 1927.
SiIII: A. Fowler, *Philosophical Transactions of the Royal Society*, A, **225**, 1, 1925.
SIII: M. Gilles, *Annales de physique*, **15**, 267, 1931.

able line); in the last column are given the identifications with the atom, the laboratory wave-length, and the laboratory intensity.

Again several of the lines are blended, but many of them are unblended, and some of these are among the strongest features of this spectral region. The only previous measures of these lines, as far as the writer is aware, are some made by C. D. Shane on plates taken by him and Dr. W. H. Wright, and communicated to the writer

by letter. The rather high dispersion available for the material in Table I (19 A/mm at 3700 A) gives an assurance that the stellar wave-lengths are fairly reliable.

The strongest unidentified line in this region is at 3694.22; it is easily visible in the spectrum of 10 Lacertae, and was measured in β Canis Majoris and β Cephei as well. It is undoubtedly a line of some element whose properties, excitation, etc., are very comparable with those of *O*III.

OBSERVATORY
UNIVERSITY OF MICHIGAN
June 10, 1932

REVIEWS

New General Catalogue of Double Stars within 120° of the North Pole. By ROBERT GRANT AITKEN in succession to the late ERIC DOOLITTLE. "Carnegie Institution of Washington Publications," No. 417, 1932. Pp. lxviii+1488. Two vols. Paper, $13; cloth, $15.

With the appearance of this welcome two-volume catalogue the lengthening gap in the literature on the subject since the appearance of Burnham's *General Catalogue of Double Stars* in 1906 ("Carnegie Institution, Washington Publications," No. 5) has been bridged. From 13,665 entries in the earlier catalogue, which is henceforth designated as *BDS*, we pass to 17,180 in the new catalogue for which the author decided upon the designation *ADS* after consulting the Committee on Notations of the International Astronomical Union. This shows a considerable growth in the field during the interval of two decades, the more so because in the present compilation the limit of declination has been put 1° farther north and the maximum separation set down within narrower limits than was the case in Burnham's catalogue. The new limits depend on the empirical relation between apparent magnitude (m) and angular separation given by

$$\log \rho = 2.8 - 0.2m ,$$

corresponding to 10″ for 9^{M}. This is amply sufficient for all needs—in fact, much more inclusive than would nowadays be considered desirable in the preparation of a catalogue of new double stars. The present work embodies all the observational material that has been published since the appearance of the *BDS* up to the epoch January 1, 1927. As the author recalls in the Introduction, this big undertaking was transferred to his shoulders in 1920, when a premature death took away E. Doolittle, to whom Burnham had intrusted the care of listing systematically all the new material that was published in the field of double-star astronomy. It was indeed a heavy responsibility to take on this stupendous task in addition to the responsibility of directing one of the most important observatories. All double-star astronomers feel grateful to Professor Aitken for having undertaken it and carried it through so successfully in a relatively short time. No living man was better qualified than he for the work; he

has contributed personally a major part to the field, and his sound judgment was a safeguard that he would do the wisest thing in settling some of the difficult points encountered from the start, such as what to include and what to omit, how to condense the material so that it would not become unmanageable and yet leave enough so that the essential data remained available.

As compared with the previous publication (*BDS*), several welcome improvements have been introduced: (1) All the material relating to one object is found in a single place instead of in two separate volumes, which were hard to handle. (2) All star positions are given for the two standard equinoxes 1900 and 1950 instead of for the odd equinox 1880; the two dates given take care of the precession and do away with the necessity of referring to separate tables. (3) While remarks about the character of the star have been largely omitted, great care has been taken to add all information such as orbital computations, spectral type, radial velocity, proper motion, trigonometric and dynamic parallaxes, as well as determinations of mass or variability, so that each star is completely characterized from all points of interest. (4) Normal places rather than individual yearly means are given whenever the nature of the motion warrants such a treatment, and especially when the number of superfluous measures is large. How much the author has condensed the material by adopting this policy can be judged from the fact that three years of measures on the slow pair Castor have been combined in one mean resulting from 168 individual observations. In doing so the author has saved many pages and kept the publication down to a reasonable size and price. (5) Instead of giving for each star the detailed references of the literature as was done in the *BDS*, only the names of the observers, or rather their abbreviations, are used. This again has saved a large amount of space and expense by avoiding the well-known Burnham italics. It is true that it is a little more laborious to find the references, but these are listed fully for each observer in the Introduction, and anyone familiar with the subject will locate the sources at once. It struck the reviewer as a little inconvenient that the observers are listed alphabetically by full name rather than in alphabetical order of abbreviation. The very active observer van den Bos is designated by *B*. In looking up the reference it was noticed that this abbreviation comes seventeenth in rank among the *B*'s, after "Bar," "Brt," "Btz," etc. This is a little confusing when one looks for the less common names: my curiosity to know who is designated as "FBn" on page 554 under No. 6645 could not be satisfied by scanning over the list of observers.

In regard to the designation *B* for van den Bos, the choice seems some-

what unfortunate since the name *BDS*, used throughout the volumes to designate Burnham's General Catalogue, seems to imply that *B* stands for Burnham, which is not the case since the more characteristic β used for so many years to designate this pioneer has been adhered to in the references.

Many will miss the familiar diagrams which in the *BDS* bring out a glance how far the motions have developed. The necessity of economizing in bulk and expense is again enough of a justification for the omission of this feature which anyone can secure for himself in a few minutes.

Among the new objects added since the publication of the *BDS*, there are many hundreds which have not been found from observations at the telescope but from the inspection of the rectilinear co-ordinates given in various sections of the *Astrographic Catalogue*. The increasing use of the latter for astrometric purposes has brought out a large number of such pairs; most of them are rather wide and the relative positions deduced from the *X* and *Y* co-ordinates are naturally coarse compared with micrometric measures, or more especially measures on plates obtained from telescopes of long focus. While the *Astrographic Catalogue*, therefore, is not a powerful means of discovery of new pairs, it is invaluable when used for the purpose of identification. In fact, no observer recording an uncatalogued new pair too faint to be in the *Bonner Durchmusterung* should fail to identify the object in the *Astrographic Catalogue*. This will at the same time furnish a precise position and avoid all difficulty in later identification. Let us take as an example the star ADS 95 which was found by W. Bowyer at Greenwich in 1908. Looking up the Paris zone $+20°$, we find at once the two components listed as $+20°$, 0^h0^m, 176 and 177, from which we secure the early position:

$$1894.90 \qquad 52°.2 \qquad 3''.17 \qquad 1 \text{ plate}.$$

From the same data we further obtain the accurate position of the primary star:

$$\alpha_0 = 0^h3^m11^s.72, \qquad \delta_0 = 19°55'11''.2 \ (1900),$$

which differs by sixteen seconds in right ascension from B.D.19°5 with which the Greenwich observer identifies the double by mistake.

Hundreds of uncertainties in position and identification can thus be eliminated, but this laborious task should be done by the individual discoverers. The editor of the *Catalogue* could hardly have been expected to enter into these intricacies; in many cases of insufficient identification the pairs are hard to find in the sky—in fact, have almost to be rediscovered.

When a double star is found in the *Astrographic Catalogue* and its rela-

tive position computed from the rectilinear co-ordinates given, it seems a little odd to credit the "discoverer" with as many nights of observation as there are plates on which the object is identified. In this case the discovery, if such it might be called, has probably been made during the day at the writing desk, and it might be advisable to designate the number of plates by p instead of by n, thus distinguishing the relative polar co-ordinates secured from the astrographic plates from those resulting from micrometric measures at the telescope.

But these are trifles. We have here before us two volumes the appearance of which will mark another milestone in the progress of double-star astronomy. It will have the most stimulating influence on its further development by bringing into evidence those objects that have been unduly neglected, those that require special attention because they enter into a critical phase of their motion, and perhaps most of all those that have been observed far too often, thus wasting many hours of night work that could be used more fruitfully.

The printing of the *Catalogue*, which was done by the Washington Typographers, Inc., is of the usual high standard of the Carnegie Institution. Very few errors have been noticed by the reviewer in glancing over the many pages of the work.

G. VAN BIESBROECK

Joseph Fraunhofers Leben, Leistungen und Wirksamkeit. By MORITZ VON ROHR. Leipzig: Akademische Verlagsgesellschaft M.B.H., 1929. 8vo. Pp. xx+233. RM. 13, unbound; RM. 15, bound.

This biography of Fraunhofer is based upon a large amount of new bibliographical material, and represents an important addition to the literature on the history of science. There are five parts:

1. The external circumstances of the life of Fraunhofer
2. Fraunhofer as optician; (*a*) improvement of working methods, (*b*) Fraunhofer as computational optician, (*c*) improvements by P. L. Guinaud and J. Fraunhofer, (*d*) Fraunhofer's mechanical work
3. Fraunhofer's scientific achievements
4. The Optical Institute considered from the point of view of business: (*a*) the production of glass, (*b*) the manufacture of telescopes and microscopes
5. Fraunhofer in history

Part III will be especially interesting to astronomers; it describes Fraunhofer's work on reflecting telescopes, his spectroscopic studies of the sun and stars, his discovery of dark lines in diffraction spectra, etc.

OTTO STRUVE

A Text-Book on Spherical Astronomy. By W. M. SMART. Cambridge: University Press, 1931. Pp. xi+414. Figs. 146. $7.00.

This book fills a need in most of our colleges and universities where a course is offered in this subject. Previous texts have been based almost entirely on Chauvenet's book, and many have been little more than adaptations of the material found there. While the fundamental principles of spherical astronomy are given in this new book, there has been included a discussion of several topics which have become of increasing importance to students of astronomy, such as astronomical photography; binary star orbits; heliographic co-ordinates; proper motions; solar motion; radial velocity; and statistical parallaxes. The author states that the book has been based "on lectures that are given each year in the University of Cambridge and a parallel course of instructions in practical astronomy." It is written for students, but it will be found to be a convenient reference book on the desk of any astronomer.

The opening chapter deals with spherical trigonometry. The usual formulae are derived in a particularly clear and straightforward manner, and as these formulae form the mathematical basis of the text, a good foundation is thus obtained for the further study of it. One of the characteristics of the book is the ease with which one follows the development of the formulae that are given. The author seems to have a lucid, concise, and attractive way of presenting his material. There is no need to discuss here the merits of the subject matter usually found in the ordinary text other than to say that it is wholly adequate.

The diagrams illustrating the celestial sphere are well done. While some of the other figures in the text leave something to be desired, the student will find a good arrangement of the drawings and will, in the main, follow them with ease. It is to be regretted, however, that more careful attention was not paid to the drawings having to do with instruments; Figures 32 and 106 should certainly be redrawn in the following editions. There will be a feeling on the part of some teachers that not enough attention has been paid to astronomical instruments and practical astronomy in general. However this may be, the text as it is written would probably be too long a treatise, if such material had been included. As it is, the parts devoted to practical astronomy are less attractive than the rest of the book.

The chief appeal of the text is the inclusion of such material as the measurement of astronomical photographs. The reductions of such measures are clearly and carefully explained. In the chapter on "Binary Star Orbits," both visual and spectroscopic binaries are introduced. Here the treatment seems sufficient for one who is for the first time considering

these problems. The chapter dealing with the determination of positions at sea gives an added interest to the text and will appeal to students. The inclusion of a discussion of heliographic co-ordinates will supply a need that has been felt by more than one teacher.

At the close of each chapter is a list of well-chosen exercises. These will greatly assist in fixing in mind the material presented. Reference is made throughout the book to the 1931 *Nautical Almanac*. While there are minor changes and criticisms which might be offered, they seem to be comparatively unimportant. The text is an admirable one, and will be welcomed by professional astronomers as well as by those who are teaching the subject.

C. C. CRUMP

Grundlagen der Erdbebenkunde. By B. GUTENBERG. "Sammlung Bornträger," Band XII. Berlin: Verlag Bornträger, 1927. Pp. 189.

This book is a useful introduction to the study of earthquakes. It begins with a list of the more important devastations caused by earthquakes from 1348 in the town of Villach to the one in 1923 in Sagami Bay, Japan, which resulted in the destruction of large parts of Tokyo and Yokohama and caused the deaths of more than a hundred thousand people.

The successive chapters are devoted to: (1) a general description of the effects of earthquakes; (2) the origin of earthquakes; (3) the transmission of waves through the earth; (4) the construction of seismographs; (5) the interpretation of seismograph records; (6) the determination of the foci; (7) small seismic tremors; (8) the prediction of earthquakes.

O. STRUVE

Astronomische Beobachtungsmethoden. By JOACHIM STOBBE. "Handbuch der biologischen Arbeitsmethoden," Abt. II, Teil 2, Heft 11. Berlin: Urban & Schwarzenberg, 1931. Pp. 179. RM. 11.

This account of the research methods used in modern astronomy is intended chiefly for biologists, but it will also be read with interest by astronomers. The volume is divided into two parts: (1) the measurement of star-positions and (2) the measurement of the amount and character of the radiation of celestial bodies. Part I consists of a general introduction explaining the co-ordinate systems, time, etc., and three chapters are devoted, respectively, to meridian circles, altazimuths, and parallactically mounted instruments. In Part II the introduction deals with the

fundamental ideas of photometry and spectroscopy, and three chapters are devoted to the determination of the brightnesses of the stars, to spectroscopic methods, and to special observations of the sun, such as the photography of prominences and the use of the spectrohelioscope.

O. STRUVE

Conférences d'actualités scientifiques et industrielles. Paris: Hermann & Co., 1929. Pp. viii+271. Fr. 35, unbound.

This volume combines several lectures which were given in 1929 at the Conservatoire National des Arts et Métiers, and which were intended to popularize the more recent advances in physics. The authors have reduced to the minimum the use of mathematical formulae and have devoted their attention especially to the discussion of fundamental principles. From the point of view of the astronomer, the following lectures are especially interesting: L. de Broglie ("The Recent Crisis of Wave Optics"), E. Bloch ("Atoms of Light and Quanta"), L. Dunoyer ("The Photo-electric Cell and Its Applications"), G. Ribaud ("The Radiation of Incandescent Bodies"), and L. Bloch ("The Structure of Spectra and the Structure of Atoms"). The administration of the Conservatoire National des Arts et Métiers is to be congratulated for having published this important volume.

P. SWINGS

Introduction à l'étude de la mécanique ondulatoire. By L. DE BROGLIE. Paris: Hermann & Co., 1930. 8vo. Pp. xvi+288. Pl. 1. Fr. 85, unbound; Fr. 95, bound.

The author begins this book with an account of those problems of classical mechanics which are useful in the study of wave mechanics (equations of Lagrange, Hamilton, and Jacobi). He then develops the fundamental ideas of wave mechanics and the equations for the propagation of waves in different cases (absence of field, constant field, and variable field). One chapter is devoted to the diffraction of electrons in crystals. Other chapters deal with probability as considered in the new mechanics of photons, with the uncertainty relations and with the objection of Einstein. The author also discusses the wave associated with the motion of a system of corpuscles and with the interpretation of the stability of motions in the old quantum theory and in the wave mechanics.

In this book the author has explained the transition from the old to the

new mechanics and the important modifications in our general conception of the nature of physical laws which have resulted from this transition.

P. SWINGS

Recueil d'exposés sur les ondes et corpuscules. By L. DE BROGLIE. Paris: Hermann & Co., 1930. 8vo. Pp. 80. Pl. 1. Fr. 20, unbound; Fr. 30, bound.

This book contains five lectures by the author, from November, 1927, to November, 1929. The form of exposition is very clear and instructive and the subject treated is of particular interest because it reflects the evolution of the ideas of the author on the question of determinism. Most physicists have undergone a similar evolution. The titles of the five lectures are:

1. Modern Physics and the Work of Fresnel
2. Waves and Corpuscles in Physics
3. The Recent Crisis in Wave Optics
4. Interference of Electrons versus Interference of Light
5. Determinism and Causality in Contemporary Physics

The fifth lecture is especially interesting, as it contains an excellent account of the indeterministic interpretation of the new mechanics, following the ideas of Born, Bohr, and Heisenberg.

P. SWINGS

Standard Four-Figure Mathematical Tables. By L. M. MILNE-THOMSON, M.A., and L. J. COMRIE, M.A., PH.D. London: Macmillan, 1931. Pp. xvi+245. 10*s.* 6*d.*, bound.

This is probably the most complete set of four-figure tables ever published. Two editions are available: Edition A with positive characteristics in the logarithms, and Edition B with negative characteristics. Among the tables may be noted especially addition and subtraction logarithms, natural and logarithmic functions in radians, natural and logarithmic hyperbolic functions, multiples of the modulus M, inverse trigonometrical and hyperbolic functions, the Gudermannian in radians, the inverse Gudermannian, multiples of $1/M$, the gamma function, and a table of the values of the definite integral

$$\operatorname{erf} x=\frac{2}{\sqrt{\pi}}\int_0^x e^{-x^2}dx\,.$$

The type used is especially clear, and the authors have printed the differences after each entry so that in use it is not necessary for the eye to be moved for interpolation. The differences are printed in smaller type and sacrifice nothing in the legibility of the main entries.

As can be judged from the partial contents listed above, the tables are remarkably complete, and, when considered with the pamphlet reviewed below, should include everything needed for almost any kind of computation where not more than four-figure accuracy is required.

W. W. MORGAN

Four-Figure Tables of the Natural and Logarithmic Trigonometrical Functions with the Argument in Time. By L. J. COMRIE, M.A., PH.D. London: Published by the Author, 1931. Pp. 32. 4*s*., unbound.

These tables are similar in typography to the volume mentioned above and may be considered as supplementing it. Everything said concerning the larger volume may be taken as applying to the smaller one as well.

W. W. MORGAN

Siebenstellige Werte der trigonometrischen Funktionen von Tausendstel zu Tausendstel des Grades. Bearbeitet von J. PETERS. Leipzig: B. G. Teubner, 1930. RM. 21, bound; RM. 18, unbound.

The recent increase in the use of calculating machines for orbital computation and other types of work has made the need felt for convenient tables of the natural values of the trigonometric functions. The present work is an excellent example of the kind. As the title indicates, the values are given to seven places of decimals at intervals of one-thousandth of a degree. The book is pleasing as to format and can be fully recommended.

W. W. MORGAN

Astronomische Paradoxa. By GEORG ALTER. Prague, Czechoslovakia: Calve's Universitäts-Buchhandlung, 1932. Pp. 71. Kr. 25.

This book is a collection of elementary problems on descriptive astronomy. Each problem is in the form of a paradox, which will doubtless attract the interest of the reader. In the course of each chapter the "paradox" is explained and an elementary solution is found. The prob-

lems are preceded by short introductions which explain in a very elementary form the essentials of the question. It should be mentioned that Problem IX, which deals with the deflection of light in the sun's gravitational field, suffers to some extent from the fact that the relative advantages of the different theories of light cannot be adequately explained in a few lines. But since these questions are introduced into many manuals of elementary astronomy, it is natural to find them in this collection.

K. OGRODNIKOFF

Sur une forme plus restrictive des relations d'incertitude. By LOUIS DE BROGLIE. Pp. 24. Fr. 6.

L'Existence du neutron. By IRENE CURIE and F. JOLIOT. Paris: Hermann et Cie, 1932. Pp. 22. Fr. 6.

These two pamphlets are the initial numbers of a new series, "Exposés de physique théorique," published under the direction of Louis de Broglie, whose purpose is to bring before the French scientific public in easily available form the results of recent memoirs of particular importance in theoretical physics.

The first consists of a paraphrase, with some commentation, of an article published over a year ago in the *Zeitschrift für Physik* by L. Landau and P. Peierls, which in turn is to a large extent an elaboration of ideas due originally to N. Bohr. It is shown in detail how the familiar uncertainty relations of Heisenberg are inadequate in the relativistic region; as a consequence the methods of ordinary quantum mechanics are not applicable where relativity is important, as within the nucleus. Of particular interest to the astronomer is the failure, in nuclear processes, of the law of the conservation of energy. The possible significance of this in connection with solar radiation has recently been stressed by Bohr.

The subject of the second pamphlet is not altogether unrelated to that of the first. It will be recalled that difficulties with energy balance in the nucleus were partly responsible for Pauli's speculative proposal of the neutron. In this brochure by Curie and Joliot recent definite experimental evidence for the existence of a particle with the mass of a hydrogen atom and zero charge is ably presented. There are several excellent reproductions of the authors' cloud-track photographs of the H-particles projected by neutrons.

It would be difficult to find two subjects of more timely importance than those treated in these two introductory numbers.

F. C. HOYT

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